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Chapter 5

HOT DESERTS OF EGYPT AND THE SUDAN[1]

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DEFINITION

Hot desert ecosystems cover all of Egypt and extend south to latitude 12°N in Sudan. The coastal ecosystems of the Mediterranean in Egypt are dealt with in another volume of this series (Ayyad, in prep.). These are delimited to the south by the isoline 10 of Budyko's "radiational index of dryness (D)" (Hare, 1976). In the Sudan, the boundary between the desert and more humid regions to the south is defined according to the isoline of $D=2$, which almost co
600-mm isohyet, starting at 12°N in the west with a bend to the south towards 9°N through the southern Gezira area, and northward at the Ethiopian border where it curves close to 14°N — a result of altitude. This corresponds roughly with the southern limits of the sub-desert region of UNESCO/FAO (1963), Köppen's **BW** (desert) region and Bailey's arid region (Fayed, 1966).

The bioclimatic provinces in Egypt and Sudan are defined here — with some modification — according to the system applied in UNESCO's map of the world distribution of arid regions (UNESCO, 1979). This system is based on the aridity index P/ETP, where ETP (potential evapotranspiration) is calculated according to Penman's formula. Four classes are recognized: hyperarid ($P/ETP<0.03$), arid ($0.03<P/ETP<0.20$), semi-arid ($0.20<P/ETP<0.50$), and sub-humid ($0.50<P/ETP<0.75$). These four classes are, in turn, subdivided according to the mean temperature of the coldest month and that of the hottest month of the year. Consideration is also given to the time of the rainy period relative to the temperature regime.

Accordingly, fourteen climatic provinces are distinguished in Egypt and Sudan: four hyperarid, six arid and four semi-arid (Fig. 5.1):

(1) The hyperarid provinces include all the area between 17° and 30°N, except the coastal mountains along the Gulf of Suez, and those extending along the Red Sea coast south of Gebel Elba.

(a) Hyperarid with a mild winter (mean temperature of the coldest month between 10 and 20°C), and a very hot summer (mean temperature of hottest month > 30°C), including the southwestern part of the western desert of Egypt and most of the desert of northern Sudan.

(b) Hyperarid with a mild winter and a hot summer (mean temperature of the hottest month 20–30°C) covering the eastern desert and the northeastern part of the western desert of Egypt, Gebel (Jebel) Uweinat and the northeastern corner of Sudan.

(c) Hyperarid with a warm winter (mean temperature of the coldest month 20–30°C) and a very hot summer, occupying the inland eastern desert of northern Sudan between Baiyuda and Butana.

(d) Hyperarid with a cool winter (mean temperature of the coldest month 0–10°C), and a hot summer, located around the summits of the Sinai mountains (see Appendix I).

The rain in these provinces is less than 30 mm yr^{-1} and is occasional and unpredictable.

(2) The arid provinces include the following sections:

(a) The northern section with winter rainfall which extends along the Mediterranean coast and the

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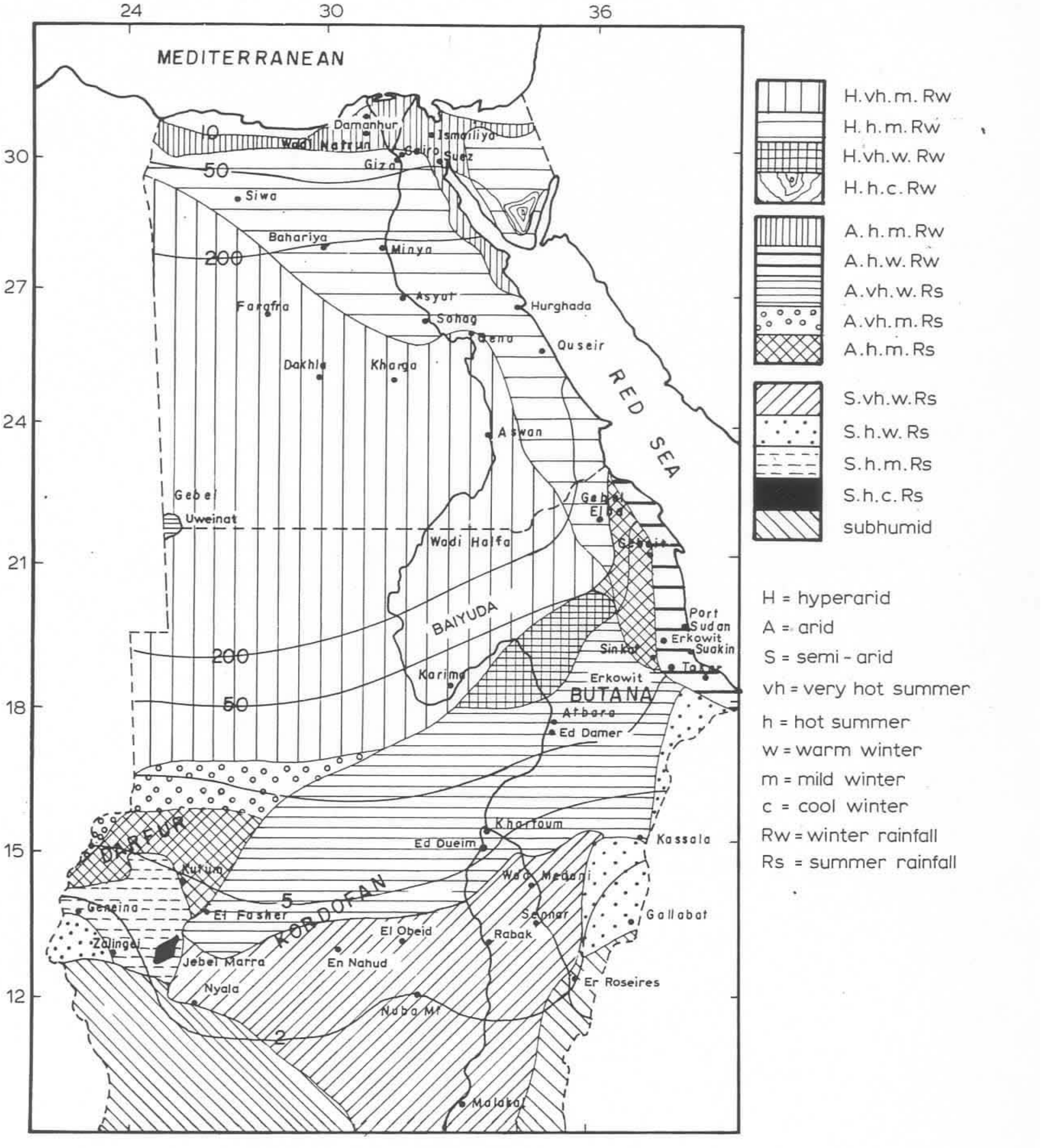


Fig. 5.1. Map of the climatic provinces in the deserts of Egypt and the Sudan, adapted from the UNESCO classifications of 1963 and 1977, with isolines of Budyko's radiational index of dryness.

Gulf of Suez. This section is distinguished into two provinces by the UNESCO/FAO map of 1963: the coastal belt province under the maritime influence of the Mediterranean, with a shorter dry period (attenuated), and the more inland province with a longer dry period (accentuated) and an annual rainfall from 20 to 100 mm. Both provinces are characterized by a mild winter and a hot summer.

(b) A southern section with winter rainfall, which

includes one province. It extends along the Red Sea coastal mountain chain from Gebel Elba to about 17°N, and is characterized by a warm winter and a hot summer.

(c) A southern section with summer rainfall which extends from the western slopes of the Red Sea mountains at 22°N to approximately 12°N. The largest province in this section, which covers a considerable area of central Sudan, is characterized by a warm winter and a very hot summer. The western part is divided into two provinces characterized by mild winters: one with a very hot summer, to the north, and one with a hot summer, to the south, with its southern limit approaching 12°N; the western slopes of the Red Sea mountains also belong to this province.

(3) The semi-arid provinces all have summer rainfall:

(a) The plains of central Sudan, south of 14°N, which are characterized by a warm winter and a very hot summer.
(b) The highlands along the Ethiopian border — but very much narrowing between the western slopes of the southern end of the Red Sea mountain chain — and the Fazoghli area where the Blue Nile leaves the Ethiopian Plateau, which are characterized by a warm winter and a hot summer. The southwestern part of Darfur also belongs to this province.
(c) The area around Jebel Marra, which has a mild winter and a hot summer.
(d) The Jebel Marra massif, which has a cool winter and a hot summer.

CLIMATE

Temperature

The temperature regime in the desert ecosystems of Egypt and Sudan is governed mainly by the latitudinal location and the maritime effect of the Mediterranean and the Red Sea. The altitudinal effect is limited to a few highlands: the Sinai mountains (see Appendix I), the Red Sea coastal chain, Gebel Uweinat at the western corner of the Sudano-Egyptian border, and Jebel Marra in Darfur Province in western Sudan. Summer is generally hot (mean of the hottest month between 20 and 30°C), or very hot (mean of the hottest month more than 30°C), and winter is either warm (mean of coldest month 20–30°C) or mild (mean minimum of coldest month 10–20°C) except on a few highlands where the winter is cool with a mean minimum of the coldest month between 0 and 10°C. In arid and hyperarid provinces the temperature along the Red Sea coast varies between a mean minimum of the coldest month of about 10°C towards the north and about 20°C towards the south, and a mean maximum of the hottest month of about 33°C towards the north and about 40°C towards the south (Tables 5.1 and 5.2). The range of variation becomes greater further inland (from about 4 to 38°C in the oases of the Western Desert and from about 14 to 40°C in central Sudan). The whole of the semi-arid provinces is located inland and the temperature regime is comparable to that of arid ecosystems of central Sudan, except the western locations in the Jebel Marra area where both minima and maxima become lower (Table 5.3). In continental locations, temperature extremes of less than −4°C in the coldest month (e.g. oases of the Western Desert of Egypt) and 53°C in the hottest month (e.g. Wadi Halfa) have been recorded. The coldest month is between December and February, and the hottest month is between June and August in hyperarid and arid provinces in Egypt. In the Sudan, temperature tends to be negatively correlated with latitude during winter: the zone of daily maximum remains over the southern parts and drops gradually northward. As summer approaches, the zone of daily maximum temperature moves northward to lie over the central plains some time during April, and by July it reaches the northern part of the country and remains there till the end of September. The Sudan "Thermal Low" tends to develop over the northeastern part, which results in excessive ground heating and the highest summer temperatures relative to the rest of the country.

Relative humidity

The relative humidity in the desert ecosystems of Egypt and Sudan is affected mainly by the relative proximity to the Mediterranean and the Red Sea. The lowest records are those of inland locations of the arid and hyperarid provinces (e.g. mean mini-

TABLE 5.1

Climatic characteristics of stations representing two hyperarid provinces (m = mean minimum temperature of coldest month; M = mean maximum temperature of hottest month)

Station	Temperature (°C)		Relative humidity (%)		Annual rainfall (mm)
	m	M	mean minimum	mean maximum	
Province a:					
Farafra (Egypt)	3.9	37.6	27 (May)	53 (Dec.)	1.9
Dakhla (Egypt)	4.4	38.6	25 (May)	48 (Dec.)	0.7
Kharga (Egypt)	5.9	39.4	29 (May)	50 (Dec.)	1.3
Aswan (Egypt)	9.5	42.0	18 (May)	41 (Dec.)	1.4
Wadi Halfa (Sudan)	7.8	41.3	16 (June)	39 (Jan.)	0.1
Karima (Sudan)	11.9	43.8	13 (May)	27 (Jan.)	25.0
Province b					
Sohag (Egypt)	5.4	37.5	25 (May)	56 (Dec.)	0.1
Asyut (Egypt)	6.8	36.9	22 (May)	49 (Dec.)	0.3
Minya (Egypt)	4.0	36.7	36 (May)	62 (Dec.)	0.7
Bahariya (Egypt)	4.7	36.9	37 (May)	58 (Dec.)	4.3
Siwa (Egypt)	4.1	38.0	42 (May)	61 (Dec.)	9.9
Hurghada (Egypt)	9.6	33.0	46 (June)	58 (Oct.)	4.0
Quseir (Egypt)	13.8	33.8	52 (March)	58 (Oct.)	3.4
El Tur (Egypt)	8.8	34.9	54 (March)	63 (Sep.)	9.4

TABLE 5.2

Climatic characteristics of stations representing four arid provinces (m = mean minimum temperature of coldest month; M = mean maximum temperature of hottest month)

Station	Temperature (°C)		Relative humidity (%)		Annual rainfall (mm)
	m	M	mean minimum	mean maximum	
Province a (Egypt)					
Damanhour	8.2	35.7	60 (May)	72 (Dec.)	90.4
Wadi Natrun	7.3	36.5	24 (May)	43 (Dec.)	45.0
Isma'iliya	7.1	35.1	38 (April)	63 (Feb.)	37.7
Suez	8.7	36.5	45 (May)	61 (Dec.)	23.6
Giza	6.4	34.8	53 (May)	73 (Nov.)	20.2
Province b (Sudan)					
Port Sudan	19.2	40.9	51 (June–July)	74 (Nov.)	106.0
Tokar	19.7	42.5	35 (July)	68 (Jan.)	85.0
Province c (Sudan)					
Atbara	14.0	42.8	14 (May)	30 (Dec.)	70
Khartoum	15.2	41.9	14 (April)	55 (Aug.)	163
Kassala	15.9	41.2	32 (April)	60 (Aug.)	327
Ed Dueim	14.4	40.9	22 (March–April)	59 (Aug.)	328
El Fasher	9.8	39.5	16 (April)	85 (Aug.)	298
Province d (Sudan)					
Gebeit	14.8	38.5	30 (June)	65 (Dec.)	120

TABLE 5.3

Climatic characteristics of stations representing three semi-arid provinces (m = mean minimum temperature of coldest month; M = mean maximum temperature of hottest month)

Station	Temperature (°C)		Relative humidity (%)		Annual rainfall (mm)
	m	M	mean minimum	mean maximum	
Province a (Sudan)					
Wad Medani	14.3	41.2	15 (April)	63 (Aug.)	401.0
El Obeid	11.6	39.1	20 (March)	66 (Aug.)	368.0
Rabak	16.0	40.6	20 (March)	71 (Aug.)	399.0
En-Nahud	14.6	39.3	21 (March)	64 (Aug.)	403.0
Sennar	15.1	41.9	21 (April)	64 (Aug.)	454.0
Er Roseires	15.9	40.8	22 (March)	79 (Aug.)	808.0
Province b (Sudan)					
Gallabat	15.5	39.4	–	–	907
Province c (Sudan)					
Geneina	11.0	39.3	21 (Jan.)	75 (Aug.)	546
Zalingei	6.1	37.2	20 (March)	69 (Aug.)	650
Nyala	16.1	37.2	14 (March)	66 (Aug.)	498
Malakal	18.1	39.1	20 (Feb.)	74 (Aug.)	826

mum of 13% and mean maximum of 27% at Karima), and the highest records are those of locations closer to the Mediterranean coast and in the Nile Delta within the arid province (e.g. mean minimum 60% and mean maximum of 72% in Damanhur). The lowest records of relative humidity are generally those of late spring in all provinces, whereas the highest records are those of late autumn and early winter in provinces with winter rainfall, and summer in provinces with summer rainfall (Tables 5.1–5.3).

Rainfall

In general, four rainfall belts may be characterized in the desert ecosystems of Egypt and Sudan: (1) the Mediterranean coastal belt; (2) middle Egypt, with latitude 29°N as its southern boundary; (3) upper Egypt and north Sudan, with latitude 18°N as its southern boundary; and (4) the central Sudan (Hurst, 1952, as quoted by Kassas, 1953a). The first and second belts have a winter rainfall (Mediterranean regime); the rainy season extends from November to April, though mainly concentrated in December and January. These belts correspond roughly to the attenuated and accentuated arid provinces of northern Egypt, where the average annual rainfall ranges from 100 to 150 mm in the attenuated arid province, and from 20 to 100 mm in the accentuated arid province (Table 5.4). It extends further south along the Gulf of Suez to 26°N due to the orographic influence of the Red Sea coastal mountains. The third belt is almost rainless; it corresponds roughly to the hyperarid provinces. Rain at the centre of this belt (approximately between 20° and 27°N) is not an annually recurring incident — 10 mm may occur once every ten years. The rainfall increases gradually both to the north until it reaches about 20 mm at the borders with the arid provinces of Egypt (at Giza) where it is definitely winter rainfall, and to the south up to the town of Karima at the northern limit of the arid provinces of the Sudan where the tropical (summer rainfall) and Mediterranean regimes merge or alternate from year to year. The fourth belt represents the northern boundary of the summer rainfall regime and covers most of the arid provinces of the Sudan. Within this belt, the distribution of the mean annual precipitation decreases northward in a marked negative correlation with latitude (Malakal 826 mm, El Obeid 268 mm, Khartoum

163 mm, Atbara 70 mm). This pattern is modified under the maritime influence of the Red Sea, and the orographic influence of the Ethiopian Plateau and the chain of the Red Sea coastal mountains, where the Mediterranean climatic regime penetrates southward up to the Sudan–Eritrean border (18°N) beyond its latitudinal limit in the continental Sahara. Over this part of the Sudan, the annual isohyets tend to extend further north. A major contributing element to this increase in rainfall over the latitudinal average is the inter-tropical convergence zone which normally extends further north over the eastern parts than over the central or western parts of the Sudan (El-Tom, 1975). This allows the moist winds to advance earlier in summer over these parts and to stay longer. To this may be added the development of the "Sudan Thermal Low" which attracts this moist air from the south, and also the deflexion by the Ethiopian Plateau of this moist air to cover wider areas further north. The Ethiopian Plateau also acts as a barrier which intercepts the southwesterly winds and prevents them bringing their summer rainfall to the coastal land. The amount of rain in this part of the Sudan therefore depends primarily on latitude and distance from shoreline. Thus, Mediterranean, tropical and alternating Mediterranean and tropical regimes all occur within short distances from the Red Sea coast: Erkowit coastal plateau with summer and winter rainfall, Suakin Old Port with winter rainfall, and Sinkat on the inland plateau with summer rainfall (Table 5.4). Other local modifications of the latitudinal pattern of rainfall in the Sudan are produced by the

TABLE 5.4

Evaporation, evapotranspiration and moisture deficiencies, as calculated by Penman's and Turc's formulae, for stations representing hyperarid, arid and semi-arid desert ecosystems of Egypt and the Sudan; Emberger's pluviothermic coefficient (Q) is included as an index of aridity

Station	Piche evaporation (mm day^{-1})		Potential evapotranspiration (mm yr^{-1})		Moisture deficiency (mm yr^{-1})		Q
	mean minimum	mean maximum	Penman	Turc	Penman	Turc	
Hyperarid provinces							
Dakhla (Egypt)	7.9 (Jan.)	24.3 (Jan.)	1678	2388	1677	2387	0.19
Aswan (Egypt)	3.6 (Jan.)	21.8 (June)	2390	2706	2389	2705	0.27
Wadi Halfa (Sudan)	8.8 (Jan.)	21.4 (June)	2108	2492	2108	2492	0.07
Karima (Sudan)	11.7 (Jan.)	21.2 (May)	2293	2634	2268	2609	1.14
Asyut (Egypt)	7.2 (Dec.)	23.2 (June)	2066	2132	2066	2132	0.13
Minya (Egypt)	4.5 (Jan.)	15.0 (June)	1846	1802	1845	1801	0.19
Bahariya (Egypt)	5.1 (Dec.)	14.0 (June)	1742	2015	1738	2014	0.48
Arid provinces							
Suez (Egypt)	4.8 (Jan.)	14.0 (June)	1997	1742	1973	1718	1.20
Giza (Egypt)	5.6 (Dec.)	14.8 (June)	1592	1582	1572	1562	1.10
Port Sudan (Sudan)	7.1 (Oct.)	14.5 (July)	1909	1708	1803	1602	2.84
Atbara (Sudan)	13.4 (Dec.)	20.9 (May)	2005	2495	1935	2425	2.01
Kassala (Sudan)	6.5 (Aug.)	15.7 (April)	1785	2152	1458	1825	4.63
El Fasher (Sudan)	5.9 (Aug.)	15.1 (April)	1802	2243	1504	1945	4.11
Semi-arid provinces (Sudan)							
Wad Medani	7.2 (Aug.)	23.1 (April)	2155	2326	1754	1925	4.98
El Obeid	6.0 (Aug.)	17.8 (April)	2037	2243	1669	1875	4.74
En Nahud	5.4 (Aug.)	19.8 (March)	1825	2225	1422	1822	5.22
Geneina	3.8 (Aug.)	21.8 (March)	1876	2208	1330	1662	5.69
Zalingei	2.9 (Aug.)	14.0 (April)	1815	2103	1165	1453	6.28
Malakal	3.0 (Aug.)	19.2 (Febr.)	1842	1884	1016	1058	8.08

orographic effects of Jebel Marra and the Nuba Mountains. A noticeable increase in rainfall occurs on the western windward sides, and distinct rain-shadow conditions prevail on the eastern leeward sides, as the main rain-producing winds approach these areas from a southwesterly direction. This is especially obvious in the Jebel Marra mountain area, which runs as a compact block for several hundred kilometres across the general trend of the rain-producing winds, and influences a wider area than the isolated hills of the Nuba mountains, which influence limited discrete areas with cellular rainfall patterns.

The orographic influence by the Red Sea mountains, on the other hand, results in rain-shadow conditions on the western side, and an increase in rainfall on the eastern side, since the main rain-producing winds in this area come with a marked intensification during winter from a northeasterly direction. Thus, across the Red Sea region the annual isohyets bend northward along the eastern slopes, and reach their maximum northern positions over the summit of the mountains. Further west, the isohyets bend sharply southward, indicating the presence of rain-shadow conditions on the western slopes. However, this pattern is likely to be reversed under the influence of the southwesterly winds during late summer.

One of the major features of rainfall in arid and semi-arid regions, other than being scanty, is its great temporal variability. Percentage variability (average deviation of annual precipitation from the mean, expressed as percentage of the mean) is greatest in the hyperarid provinces (e.g. Siwa 83%). In the arid provinces the percentage variability ranges from 18% at Ed Dueim near the semi-arid provinces to 65% at Giza and 56% in Port Sudan, which are close to the hyperarid provinces in Egypt and Sudan. Sennar, in one of the semi-arid provinces of the Sudan, has an annual rainfall variability of 16%, and Er Roseires, located at the limit of the sub-humid region, 13%.

Wind

Wind circulation over Egypt and Sudan is controlled by three permanent high-pressure belts: the Azores, the Indian subtropical, and the South Atlantic subtropical. Besides these, a permanent low-pressure belt, the doldrums, crosses the African continent in the vicinity of the equator. Seasonal high- and low-pressure systems also alternate over the continental mass, the Red Sea, the Mediterranean, and the Arabian Peninsula.

Accordingly, two main flows may be distinguished: one originating in the north (the northerlies) and the other in the south (the southerlies). The tropical highs over the Indian and the Atlantic oceans are the original sources of the southerlies. When these reach the Sudan they bring rain.

In winter, the Sahara high-pressure system dominates the circulation and the northerlies bring cool dry air from the North African continental source region, though occasionally the Arabian high brings warmer air to the eastern parts of the Sudan. Both of these types are occasionally interrupted by east–west depressions along the Mediterranean, and replaced by cold dry air from the Eurasian landmass. In spring and autumn, the Arabian high is more dominant in the east and the effect of Mediterranean depressions is rarely felt as far south as central Sudan. Air from both the North African and the Arabian sources is considerably warmer than in winter. In summer, the Saharan high is again dominant bringing hot dry air.

Occasionally, very hot dust-laden winds blow over Egypt (*khamsin*) and Sudan (*haboub*) which have numerous environmental consequences including a possible effect on climate, soil formation, ground-water quality and crop growth (Goudie, 1978). They may create problems including substantial degrees of deflation and erosion, the spread of diseases through pathogen transport, the suffocation of cattle, disruption of transport and damage to property. Visibility during these storms is reduced substantially (below 1000 m). Dust deposition rate due to these storms in Egypt has been estimated by Oliver (1946, as quoted by Goudie, 1978) to be 371 t km^{-2} in individual falls. In the early seventies, Youssef et al. (1975) estimated a normal rate of 131 t km^{-2} yr^{-1} in Cairo, which increased to 2236 t km^{-2} yr^{-1} (17-fold) in areas near quarries. The grains were of calcite, quartz, amorphous silica and very little montmorillonite.

Moisture regime

The evaporative power of the air in the hyperarid provinces of Egypt and Sudan, as measured by

the Piche evaporimeter, varies in January from 3.6 mm day^{-1} in Aswan to 11.7 mm day^{-1} in Karima, and in June from 14.0 mm day^{-1} in the Bahariya Oasis to 24.3 mm day^{-1} in the Dakhla Oasis (Table 5.4). In arid provinces, the mean minimum evaporation rate during winter is, in general, within the same range as in the hyperarid provinces, whereas in summer, the mean maximum — except in Atbara which is not far from the limits of the hyperarid provinces — is notably lower (from 14.0 mm day^{-1} in Suez to 15.7 mm day^{-1} in Kassala). In semi-arid provinces, which all have summer rainfall, the ranges of variation in both the mean minimum and the mean maximum evaporation rates are again about the same as those in the hyperarid provinces, but occur in August and April respectively.

The annual potential evapotranspiration is, in general, also lower in arid provinces than in hyperarid and semi-arid provinces (Table 5.4). The lowest is that of Giza (592 mm according to Penman's equation, and 1582 mm according to Turc's equation). However, the moisture deficiency (potential evapotranspiration − precipitation) is much lower in semi-arid provinces, on account of the higher annual precipitation (compare, for example 1016 mm in Malakal with 2389 mm in Aswan). The duration of the dry season as indicated by the ombrothermic diagrams (Fig. 5.2) varies from five months (May–September) in Malakal (semi-arid) to the whole year in all hyperarid and some arid stations.

GEOMORPHOLOGY AND SURFACE DEPOSITS

The Nile, a perennial stream which makes its way over thousands of kilometres of desert to the Mediterranean, divides Egypt and Sudan into two distinct geomorphological regions: the eastern dissected plateau, and the western flat expanse which forms an extension of the Libyan Desert. Although the land to the east of the Nile forms one geomorphological region, it is divided geographically into the Eastern Desert and the Peninsula of Sinai, separated by the Gulf of Suez. The Sudano-Egyptian desert may therefore be distinguished into three geomorphological provinces: (1) the Eastern Desert; (2) the Western Desert; and (3) the Sinai Peninsula (see Appendix I).

Eastern Desert

The Eastern Desert includes the Arabian, Atabai and Nubian deserts. It consists essentially of a backbone of high and rugged igneous mountains running parallel to the Red Sea coast from the Ethiopian Plateau northward up to Gebel Umm Tinassib (28° 30′N). These mountains do not form a continuous range, but rather a series of mountain groups with some detached masses and peaks, and are flanked to the north and west by intensively dissected sedimentary limestone plateaux (Said, 1962). To the north, extensive and lofty limestone plateaux extend along the Gulf of Suez. They comprise South Galala (1464 m), North Galala (1273 m) and Gebel Ataqa (871 m), which are separated from each other by broad valleys. The formations of these limestone plateaux are mainly Upper Eocene (Bartonian) and Middle Eocene (Lutetian). The former includes a series of sands, marls, clays and marly limestones which are softer, more easily eroded, and contain larger amounts of gypsiferous and ochreous materials. The Middle Eocene formations include various types of limestone which are more solid and contain a number of hard dolomitic bands (Kassas and Girgis, 1964). They form the main bulk of the northern limestone plateaux. This Eocene desert adjoins on its north border sand and gravel formations of the Oligocene (Kassas and Imam, 1959). Its western side is bordered in the north by alluvial deposits of the Pleistocene terraces of the Nile, and in the south by discontinuous patches of Pliocene and Plio-Pleistocene deposits. The southern group of limestone plateaux extends from Asyut southward to Qena and includes Lower Eocene formations represented by Gebel Abu Dukhan (1705 m), Gebel Qattar (1963 m), Gebel Shayib el Banat (2187 m) and Gebel Umm Enab (1782 m).

The basement complex formations to the south of Qena separate the Red Sea coastal plain from the Nubian Sandstone (mainly Cretaceous) fringing the Nile Valley. These formations are represented by the Gebel Nugrus group (1200–1500 m), the Gebel Samiuki group (1280–1977 m), and the Gebel (Jebel) Elba group on the Sudano-Egyptian border (22°N). This latter is an extensive group of granite mountains comprising Jebel Elba (1428 m), Jebel Shindeib (1911 m), Jebel Shindodai (1526 m), Jebel Shillal (1409 m), Jebel Makim (1871 m), and

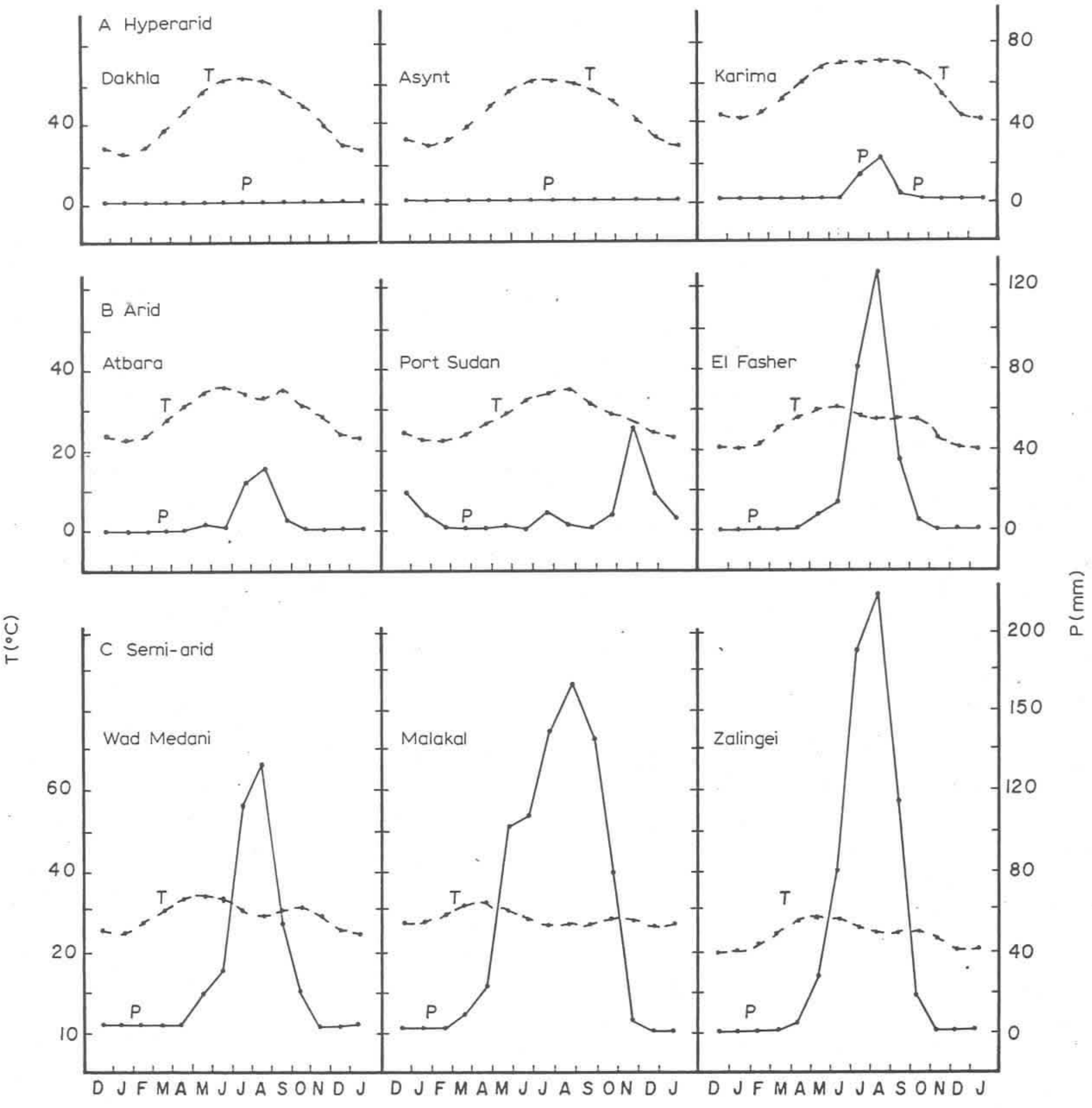


Fig. 5.2. Ombrothermic diagrams for stations representing the hyperarid, arid and semi-arid provinces of Egypt and the Sudan.

Jebel Asoteriba (2217 m). To the south of this group in the northeastern corner of the Sudan is Jebel Erba (2217 m). To the west, these groups of mountains are flanked by lower ever-broadening Nubian Sandstone plateaux, which are horizontally lying sedimentaries.

Palaeodeposits formed *in situ* cover extensive areas of the limestone plateaux in the northern and middle parts of Egypt, and of sandstone plateaux in southern Egypt and northern Sudan. These deposits form erosion pavements described by Kassas (1953b) and Kassas and Girgis (1964), *hamada* desert, and rocky erosion surfaces. The sand and gravel desert that extends east of the Nile Delta to the Suez Canal is composed of fluviatile palaeodeposits which belong to the Oligocene,

non-marine Miocene or Pliocene (Shukri, 1953; Shukri and Akmal, 1953).

The most pronounced geomorphological feature of the whole Eastern Desert of Egypt and Sudan is its dissection by valleys and ravines. While eastward drainage of highlands to the Red Sea is by numerous independent wadis, the westward drainage to the Nile Valley mostly coalesces into a relatively small number of great trunk channels. The most notable of the wadi systems dissecting the limestone plateau is Wadi el Asyuti which pours into a depression joined to the Nile Valley. Wadi Qena is also one of the most notable features of the limestone desert; the north–south course of its stream is unique. The main wadi systems dissecting the Nubian (Sandstone) Desert are the Wadi Allaqi system (the most extensive in the Egyptian deserts) to the north, and the Wadi Kurusku, Wadi Shaturma, Wadi Hamid, Wadi Nugdeib and Wadi Abusku group to the south. The mouths of these wadis are in direct contact with the Nile. Further south, Khor Arbaat north of Port Sudan is one of the few permanent streams in the Red Sea hills of the Sudan. Its water flows as far as the foothills and may reach the sea in torrential floods (3 million m^3 for every 1 mm run-off) during exceptionally wet years. A large proportion of this flood water is stored in the wadi-fill deposits, and supplies the silt for the Arbaat Delta (Kassas, 1957). Khor Baraka at 18°N also has produced, by its ephemeral floods, the silt-covered Tokar Delta (154 000 ha in area).

Between the highlands and the shoreline, the coastal plain slopes gently. It varies in width, while it is practically non-existent in certain parts of the Gulf of Suez; it ranges from 8 to 15 km in width throughout most of its length in the Sudan. It is generally divided into a littoral salt marsh with sandy hillocks and flats of calcareous silt, and an inland desert plain. Near the hills, the desert plain is covered with coarse boulders; further away the surface sediments become less coarse. The shoreline comprises in some areas a number of bays and lagoons. In the Sudan the shoreline is formed of Recent coral reefs which have been raised above the present sea level and extend up to 2 km inland (Kassas, 1957). The shallow water, separated by coral reefs, provides the habitat for mangrove vegetation. The main plain is covered by a series of silts, sands and gravel of fluviatile origin, often with a stony surface. In places, this stony surface is buried by blown sand or washed silt. Mobile dunes of the *barkhan* type are sterile. The Recent deposits rest upon Plio-Pleistocene beds of limestone, shales, marls, clays, grits, conglomerates and gypsum (Andrew, 1948). To the north of 20°N, the Plio-Pleistocene beds form low flat-topped hills projecting through the Recent deposits. These beds rest uncomformably upon the basement complex of the Archaean rocks. Along the western margin of the plain, hills of Archaean rocks have been reduced to plain level by erosion and are now marked by residual fragments of the underlying rock type. This forms locally a desert surface of the *hamada* type as distinguished from the gravel desert of the plain and the "erosion pavements" described by Kassas (1953b).

The geology of the area to the east of Cairo was outlined by Abdel-Daiem (1971). Quaternary strata cover the major part of the area and are dominant in the Nile Valley, in the adjacent plains and in the courses of the main wadis. These strata have a maximum thickness of about 240 m, and are developed into aeolian sands as well as into fluviatile sands and gravels.

Tertiary strata occupy much of the area lying to the east of Cairo; they are essentially developed into lime facies with thin intercalations of clayey sand, and are formed under shallow marine conditions. Tertiary basalts also occur. The Tertiary succession, with a maximum reported thickness of about 800 m, is distinguished into Pliocene (200–300 m), Miocene (45 m on the Cairo–Suez Road), Oligocene (230 m in Inchas) and Eocene (375 m east of Helwan). Pliocene strata are exposed at the fringe of the Nile Valley and are referred to as marine Pliocene composed of sandy limestone and marl backed with *Ostrea cucullata* with a rich foraminiferal content.

According to this sequence, it is postulated that arms of the Pliocene gulf that occupied the Nile Valley penetrated into erosional valleys of the main wadis, which were originally formed towards the end of the Miocene. At the end of the Pliocene and in the Early Pleistocene, continued rising of the land surface in the south and the flow of fresh water into the Pliocene gulf filled this gulf with terrigenous material, so that the Nile flood plain and Delta deposits were accumulating. Pleistocene to Holocene times were marked by continual build-

ing of the Delta, the piedmont plains and eventually the flood plains. With the advent of aridity the landscape took most of its present shape.

Western Desert

The Western Desert is essentially a flat plateau with numerous closed-in depressions, except for the mountain mass of Gebel Uweinat (1907 m) on the extreme west of the Sudano-Egyptian border. To the northeast of Gebel Uweinat, a broad tract of high ground extends for more than 200 km, and slopes gradually towards the north to the depressions of the Dakhla and Kharga oases. The northern boundary of these oases is marked by a high escarpment which forms the southern edge of a great plateau of Eocene limestone (Said, 1962). This plateau rises in places over 500 m above sea level and forms the dominant feature of the major part of the Western Desert in Egypt. In this limestone plateau the great hollows containing the oases of Farafra and Bahariya are situated. To the northwest, this plateau slopes gradually towards Siwa and the great Qattara Depression, where the ground descends below sea level. To the northeast of Bahariya the plateau rises again to form Gebel Qatrani overlooking the Nile-fed depression of Faiyum. The northern limit of Siwa and the Qattara Depression is formed by a second important escarpment stretching up to the Maghra Oasis and marking the southern edge of a great Diffah Plateau of Miocene limestone (200 m) which extends to the Mediterranean. Fluviatile palaeodeposits cover the desert which extends west of the Nile Delta and embraces the district of the Wadi el Natrun depression, and the Cairo–Faiyum desert.

Whereas the northern depressions of Qattara, Siwa, Giarabub (al Jaghbub), etc., began forming during Late Pliocene times through a rather complex evolution in which the *cuesta* formations played an important role and the forces concerned were a northward inclination of strata of variable resistance, tectonic subsidence, wind erosion, and chemical weathering (Pfannenstiel 1953), to which Knetsch and Yallouze (1955) added exsudation (chemical action by ground waters, highly enriched in salts by an arid climate) as the main factor, Butzer (1965b) believed that Kurkur is not a wind-excavated hollow. Aeolian activity is everywhere apparent from small features such as lag winnowing, bedrock fretting, and sand accumulation to large-scale deflation of extensive but shallow depressions. The distinction of arid and humid landforms is apparent in part as a result of concurrent or subsequent remodelling by wind. The absence of a soil mantle may be the single most significant geomorphic phenomenon.

There are a few gullies draining from the northern edge of the plateau of the Western Desert to the Mediterranean and to the eastern edge of the Nile, but well-marked drainage systems comparable to those of the Eastern Desert are not found.

A prominent feature of the Western Desert is the parallel belts of sand dunes that extend in a north–south direction for hundreds of kilometres. Extensive flat expanses of drifted sand, especially in the south and west, have gained for the Western Desert the fame of being a sea of sand, but the total area covered by sand is in fact less than that occupied by bare rock.

Mainguet (1972), from a study of satellite photographs of the eastern Sahara, concluded that aeolian winds follow a continuous route from the vicinity of the Faiyum Depression in a NE–SW direction, turning around the mountain masses on the frontiers of Libya, Egypt and the Sudan, especially at Gebel Uweinat where they divide into a branch pursuing the Mardoghoum corridor and another branch following the east–west Mourdi Depression, south of Tibesti and ending at Bilma. Mainguet et al. (1980) gave a map showing the extent of these winds and their directions in the Sudano-Egyptian deserts, together with the location of their obstacles and fields of deposition.

In the Sudan there are watersheds separating the northern slopes of the Western Desert from the southern slopes of Darfur and Kordofan (Kutum-Dueim). The country south of this watershed is divided by the Nuba mountains into a western part sloping towards Bahr el Arab, and a narrow eastern part sloping towards the White Nile. The lower areas of the Sudan form a plain of desert erosion in the north, and a plain of accumulation or aggradation in the south (Andrew, 1948). The line between these two areas follows the Kutum–Dueim watershed, and then passes north of the Butana to Atbara. West of the White Nile and south of the margin of the northwestern desert the low ground is occupied by a vast extent of dune sand.

As can be seen from these descriptions of the geomorphology of the two main desert areas, the absence of a true soil cover is a prominent characteristic of the hot deserts of Egypt and the Sudan, and the whole Sahara for that matter. Fig. 5.3 shows a soil classification map of these deserts (and adjacent territories of the two countries) taken from the Soils Map of Africa.

VEGETATION

Considering the climatic and geomorphological regional variations in the Sudano-Egyptian deserts outlined in the previous sections, the following scheme of climatic-geomorphologic units may be suggested:

I. Hyperarid Eastern Desert region
  a. Red Sea coastal plain
  b. Limestone plateaux
  c. Basement Complex formations
  d. Red Sea wadis
  e. Sinai wadis
  f. Sinai mountains
II. Hyperarid Western Desert region
III. Arid Mediterranean Desert region
  a. Sinai plains
  b. Gulf of Suez coastal plain
  c. Wadis
  d. Gravel desert
  e. Western Desert
IV. Arid region with winter and summer rainfall
V. Arid tropical Eastern Desert region
VI. Arid tropical Western Desert region
VII. Semi-arid tropical Eastern Desert region
VIII. Semi-arid tropical Western Desert region
IX. Semi-arid tropical hill and montane region
X. Semi-arid wadi region

Each of these units includes a group of ecosystems varying in local physiographic features. In this section, the habitat and vegetation of the commoner ecosystems will be described.

I. Hyperarid Eastern Desert region

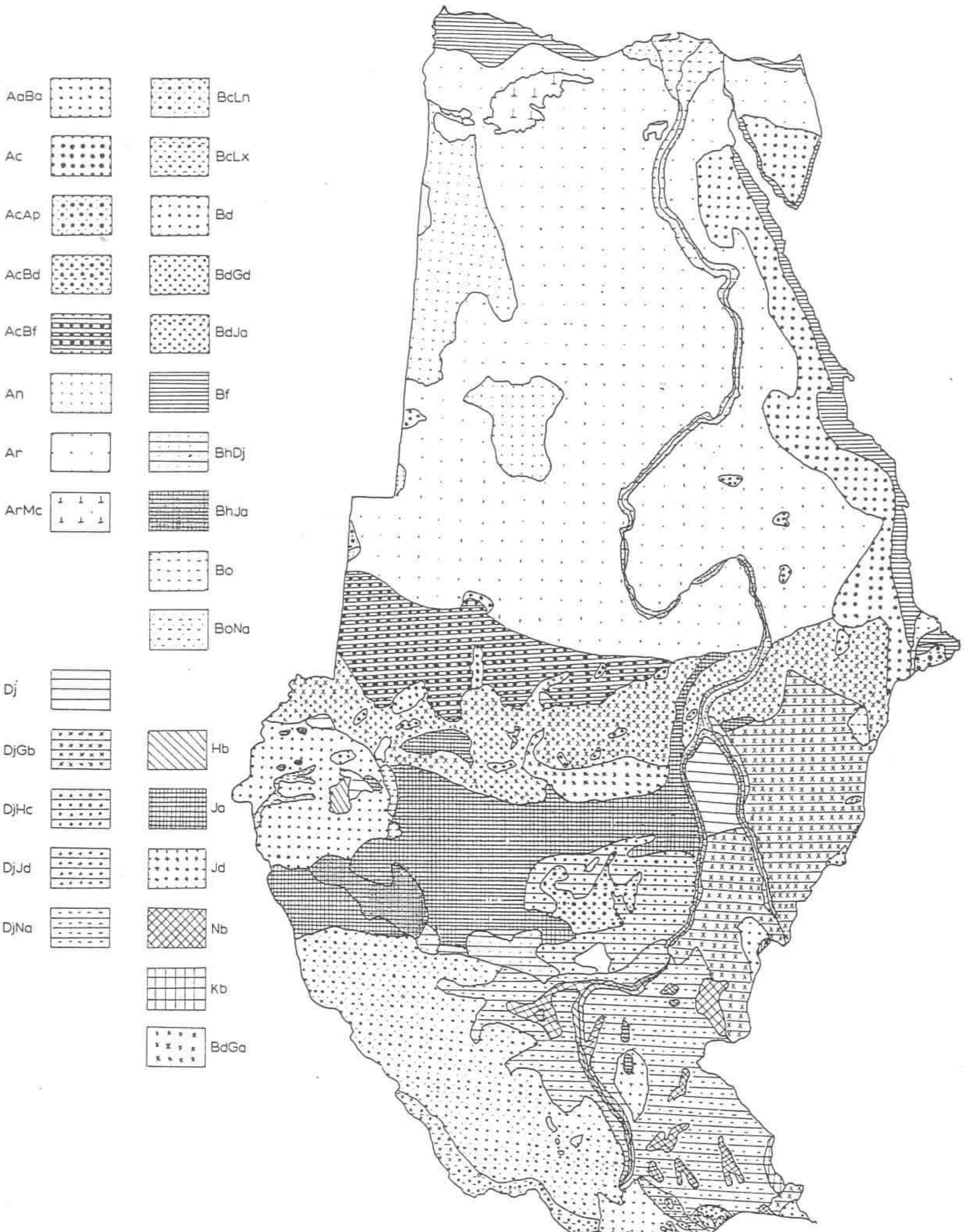
a. Red Sea coastal plain

Mangals. The shoreline morphology and climate of the Sudano-Egyptian Red Sea coast, especially south of Hurghada, seem to favour the growth of mangal vegetation (Kassas, 1957). Along the raised coral reefs there is a series of small bays that cut into the beach, and are partly land-locked by further coral reefs. These sheltered bays provide a favourable habitat for the growth of mangal vegetation, fully described elsewhere in this series (Zahran, 1977).

Avicennia marina usually grows in pure stands, but may be found mixed with *Rhizophora mucronata* as a codominant (Kassas and Zahran, 1967). Where both species grow together, *R. mucronata* forms an open layer higher than the thick and almost continuous bushy canopy of *A. marina*. In a few localities, *A. marina* grows on the terrestrial side of the shoreline, and in one locality (delta of Wadi Gimal) the bushes are partly covered with sand hillocks, a situation which is apparently due to the silting of the shoreline zone originally occupied by the mangrove. The ground layer is formed of associated marine phanerogams, such as *Cymodocea ciliata*, *C. rotundata*, *C. serrulata*, *Diplanthera uninervis*, *Halophila ovalis* and *H. stipulacea*.

The tidal mud of the mangrove vegetation is usually grey or black in colour, and is often foul-

Fig. 5.3. Soil map of the deserts of Egypt and the Sudan (after *Soils Map of Africa*, by the Commission de Coopération Technique en Afrique (CCTA), Service Pédologique Inter-Africain, Projet Conjoint No. 11, 1959.)
Symbols: *AaBa* = rock and rock debris, rock rich in ferromagnesian minerals, lithosols and lithic soils, on lava; *Ac* = undifferentiated soil, (*Ap* = desert detritus, desert pavements, transported, *Bd* = lithosols, *Bf* = undifferentiated sub-desert soil); *An* = sands (ergs); *Ar* = undifferentiated desert detritus (*Mc* = undifferentiated halomorphic soils); *Bc* = lithosols on ferruginous crusts (*Ln* = undifferentiated ferrallitic soils, *Lx* = undifferentiated yellow and red ferrallitic soils on various parent materials); *Bd* = undifferentiated lithic soils (*Gd* = brown soils of arid and semi-arid tropical regions, undifferentiated, *Ja* = ferrugineous tropical soil, on sandy parent material); *Bf* = undifferentiated sub-desert soil; *Bh* = weakly developed soils on loose sediments most recently deposited (*Dj* = undifferentiated vertisols and similar soils of topographic depressions); *BhJa* = see *Bh* and *Ja*; *Bo* = juvenile soils on recent deposits on riverine and lacustrine alluvium (*Na* = hydromorphic mineral soil): *Dj Gb* = see *DjHc* = hydromorphic tropical soils, differentiated and undifferentiated, *Jd* = ferrugineous tropical soils, undifferentiated); *DjNa* = see *Dj* and *Na*; *Hb* = eutrophic brown soils of tropical regions, not differentiated; *Ja* = see above; *Jd* = see above; *Nb* = hydromorphic and organic hydromorphic soils; *Kb* = ferrisols, on rocks rich in ferromagnesian minerals; *BdGa* = lithosols, brown soils on loose sediments.


AaBa
Ac
AcAp
AcBd
AcBf
An
Ar
ArMc
BcLn
BcLx
Bd
BdGd
BdJa
Bf
BhDj
BhJa
Bo
BoNa
Dj
DjGb
DjHc
DjJd
DjNa
Hb
Ja
Jd
Nb
Kb
BdGa

smelling. A notable difference between the tidal mangrove mud of *A. marina* and that of *R. mucronata* is the low content of total carbonate in the former as compared to the calcareous mud in the latter.

Reed swamps. The habitat of the reed-swamp vegetation of the Sudano-Egyptian Red Sea coastal plain is provided by channels and creeks at the mouths of big wadis, and areas which represent the combined influences of the brackish-water springs, such as the Ain Sokhana in Egypt (Kassas and Zahran, 1962).

The reed swamps are dominated by *Phragmites australis* and *Typha domingensis*. The latter usually inhabits areas where the soil is relatively less saline and the water not too shallow, such as estuaries of wadis that collect the occasional drainage, while *P. australis* grows in swamps close to the dry land, often with higher soil salt content (Zahran, 1966). The common associates include *Berula erecta*, *Cyperus articulatus*, *C. dives*, *C. mundtii*, *Lemna gibba*, *Samolus valerandi*, *Scirpus mucronata*, *S. tuberosus*, *Spirodela polyrrhiza* and *Wolffia hyalina*.

Salt marshes. The vegetation of the salt-marsh ecosystems is, more or less, organized into zones following the shoreline. Within any locality only a few zones are represented, each including a mosaic of several communities depending on local topography and soil conditions (Kassas and Zahran, 1967). Twelve such communities are recognized in the Red Sea coastal plains of Egypt and Sudan:

(1) The *Halocnemum strobilaceum* community of the Gulf of Suez, but not in the region further south, with *Zygophyllum album* and *Arthrocnemum glaucum* as common associates;

(2) The *Arthrocnemum glaucum* community, throughout the Red Sea coastal plain, though less common along the Gulf of Suez, with *Halopeplis perfoliata* and *Limonium axillare* as the most common associates in the southern part, and *Atriplex farinosa* in the shoreline zone;

(3) The *Halopeplis perfoliata* community, confined to the area 55 km north of Ras Gharib, with *Arthrocnemum glaucum* and *Zygophyllum album* as the most common associates;

(4) The *Limonium pruinosum* community in the region of the Gulf of Suez;

(5) The *Limonium axillare* community in isolated localities in the northern section, and as a continuous stretch south of Quseir;

(6) The *Aeluropus* spp. community confined to localities south of Quseir, and co-dominated by *A. lagopoides* and *A. brevifolius*;

(7) The *Sporobolus spicatus* community, common in the southern 100 km of Egypt and in the Sudan, with *Aeluropus* spp., *Cyperus conglomeratus*, *Limonium axillare*, *Panicum turgidum*, *Salsola baryosma* and *Sevada schimperi* as the most common associates;

(8) The *Halopyrum mucronatum* community, limited to an area 2 km long, 1030 km south of Suez;

(9) The *Zygophyllum album* community, ubiquitous in distribution and with numerous associates;

(10) The *Nitraria retusa* community, confined to the northern 650 km, and forming hillocks of sand, with *Zygophyllum album* and *Limonium pruinosum* as common associates;

(11) The *Suaeda monoica* community, which gradually replaces the *Nitraria retusa* community between 300 and 650 km from the north until, in the south, *S. monoica* becomes dominant; and

(12) The *Tamarix mannifera* community along the whole Red Sea coastal plain, in a variety of habitats, forming thickets and sand hillocks.

Desert-plain ecosystems. Six community types are recognized by Kassas (1957) in the desert-plain ecosystems of the Sudanese Red Sea coast. These communities are dominated by *Indigofera spinosa* where the surface deposits are mixed gravel and sand, and where little run-off water is received; by *Panicum turgidum* on wind-borne sand hillocks; by *Acacia tortilis* along the runnels; by *Calotropis procera* on sheets of sand drift; by *Acacia nubica* on the borders with salt-marsh zones; and by *Capparis decidua* where the main wadis sheet-flood the plain producing ill-defined deltas with soft alluvial deposits.

b. Limestone plateaux

The plateaux are represented by the mountain area of the Gebel Shayib group, the northernmost of the coastal mountains facing the Red Sea. The rich plant life of this mountain area is in contrast with the almost lifeless coastal plain. The vegetation comprises a number of community types; the following is an example demonstrating the variety

of species at Bir Um Dalfa (Kassas and Zahran, 1971): *Aerva persica*[1], *Acacia raddiana*, *Artemisia herba-alba*, *A. judaica*, *Capparis cartilaginea*, *Chrozophora oblongifolia*, *Colocynthis vulgaris*, *Cleome droserifolia*, *Fagonia tristis* var. *boveana*, *Hyoscyamus boveanus*, *Launaea spinosa*, *Lavandula stricta*, *Lindenbergia abyssinica*, *L. sinaica*, *Moringa peregrina*, *Periploca aphylla*, *Pulicaria crispa*, *P. undulata*, *Solenostemma argel*, *Teucrium leucocladum*, *Zilla spinosa*, and *Zygophyllum coccineum*.

c. Basement Complex formations

In Egypt, the highlands of the Basement Complex formations are represented by the Gebel Nugrus, Gebel Samiuki and Gebel Elba groups. Communities of *Moringa peregrina* characterize the mountain slopes of the Gebel Nugrus group. In the Gebel Samiuki area in general, the flora is much richer in species composition and in plant cover, and *Moringa peregrina* reaches higher altitudes. The flora of the Gebel Elba group is much richer than that of the Gebel Samiuki group. Three altitudinal zones of vegetation are recognized on the north and northeastern slopes of Gebel Elba: a lower zone of *Euphorbia cuneata*; a middle zone of *E. nubica*; and a higher zone of *Acacia etbaica*, *Dodonaea viscosa*, *Dracaena ombet*, *Euclea schimperi*, *Ficus salicifolia*, *Pistacia khinjuk* and *Rhus abyssinica*. Within these higher altitudes ferns, mosses and liverworts abound. The southern slopes are notably drier; plant growth is mostly confined to the runnels of the drainage system. Communities in these runnels are dominated by *Commiphora apobalsamum*. At higher altitudes individuals of *Acacia etbaica* and *Moringa peregrina* may be found (Kassas and Zahran, 1971). The vegetation of the northeastern slopes of Gebel Shindodai (Gebel Elba group) comprises four main zones from base to top: a zone dominated by *Caralluma retrospiciens*; a zone dominated by *Delonix elata*; a zone of *Moringa peregrina*; and a zone with bushes of *Dodonaea viscosa*, *Euclea schimperi* and *Pistacia khinjuk* var. *glaberrima*. The northeastern slopes of Gebel Shillal in the same group have a base zone of *Acacia tortilis* and *Commiphora apobalsamum*; a middle zone of *Acacia etbaica* and *A. mellifera*; and a top zone with patches of *Cordia gharaf*, *Dodonaea viscosa*, *Maytenus senegalensis*, *Rhus oxyacantha* and some bryophytes and ferns.

d. Red Sea wadis

The wadis of the limestone country north of Qena may be represented by the wadi draining Gebel Qattar (Gebel Shayib group), Wadi Qena and Wadi el Asyuti. The communities in the wadi draining Gebel Qattar are mostly dominated by *Moringa peregrina*. Common species are: *Acacia raddiana*, *Aerva persica*, *Artemisia judaica*, *Capparis cartilaginea*, *C. decidua*, *Cleome droserifolia*, *Fagonia tristis* var. *boveana*, *Hyoscyamus boveanus*, *Lavandula stricta*, *Leptadenia pyrotechnica*, *Lycium arabicum*, *Ochradenus baccatus*, *Periploca aphylla*, *Pulicaria undulata*, *Teucrium leucocladum*, *Zilla spinosa* and *Zygophyllum coccineum*.

In Wadi Qena, the communities dominated by *Tamarix aphylla* and *T. mannifera* occupy sandy terraces. The fringes of the main channel are occupied by a community of *Acacia ehrenbergiana* with *Aerva persica*, *Artemisia judaica*, *Leptadenia pyrotechnica*, *Pulicaria crispa*, *Salsola baryosma* and *Zilla spinosa* as common associates (Kassas and Girgis, 1972). The principal channel of Wadi el Asyuti is occupied by communities dominated by *Cornulaca monacantha* where limestone detritus of wadi fill is associated with a thin cover of aeolian sand, and *Calligonum comosum* and *Tamarix aphylla* form sand mounds and hillocks.

The communities of wadi ecosystems of the Basement Complex country are distinguished by Kassas and Girgis (1969) into four types: ephemeral, suffrutescent woody, suffrutescent succulent and scrubland types. The ephemeral community type is that of *Morettia philaeana*, with *Fagonia indica* as a consistent associate, in the small runnels of Wadi Allaqi and other wadis. The suffrutescent woody types are represented by the community of *Aerva persica* with *Cassia senna* as a consistent associate, and the community of *Indigofera argentea* with *Aerva persica* and *Fagonia indica* as common associates. Both of these communities are common in small affluents of Wadi Allaqi. The suffrutescent succulent type is represented by the *Salsola baryosma* community, with *Aerva persica* as the most common associate, in the main channel of Wadi Allaqi. Each of the scrubland types is dominated by a shrub or a tree and thus comprises at least one vegetation layer higher than 150 cm.

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[1]Now *A. javanica*.

The following are the main types:

(1) The *Acacia ehrenbergiana* community, which is the most widespread in the Nubian Desert. The local pattern of its distribution is variable. It is most preponderant in the tributaries of Wadi Allaqi with deep compact fill deposits.

(2) The *Acacia tortilis* community, which is common in the eastern part of Wadi Allaqi and the Khor system. In certain localities the growth of *Acacia raddiana* may contribute to the cover. *Leptadenia pyrotechnica* and *Maerua crassifolia* are the most common associates. It is more common in localities of coarse alluvial deposits.

(3) The *Acacia raddiana* community, which is present in all the wadis of the Nubian Desert. The most common associates are *Acacia tortilis, Balanites aegyptiaca, Leptadenia pyrotechnica* and *Salvadora persica*.

(4) The *Leptadenia pyrotechnica* community, which is confined to the montane country of the Wadi Allaqi system. Common associates include *Calotropis procera, Maerua crassifolia, Salvadora persica* and *Solenostemma argel*.

(5) The *Tamarix mannifera* community, which is common in Wadi Haimur — one of the main tributaries of Wadi Allaqi — and in Khor Arbaat. It forms pure stands on silt terraces with relatively high salt content.

(6) The *Salvadora persica* community, which is confined to the wadis of the montane country of the eastern Wadi Allaqi system. *Acacia raddiana, A. tortilis, Calotropis procera, Leptadenia pyrotechnica* and *Solenostemma argel* are common associates. It is most common in localities with soft wind-borne material.

(7) The *Balanites aegyptiaca* community which is present in Wadi Ungat and Wadi Seiga (tributaries of Wadi Allaqi). Common associates are *Acacia raddiana, A. tortilis, Calotropis procera* and *Salvadora persica*.

e. Sinai wadis

One of the most common communities on the elevated banks and slopes of the large wadis of Sinai is that dominated by *Ephedra alte*. A *Hyoscyamus muticus* community is common on silty and sandy beds, while gravelly terraces are commonly occupied by a community of *Achillea fragrantissima*. Around springs and in inundated depressions, the most common community is that of *Nitraria retusa*. A community of *Artemisia judaica* becomes common in wadi beds of compact sand derived from gravel; at higher altitudes this community becomes codominated by *Zilla spinosa* (Zohary, 1944).

f. Sinai mountains (see also Appendix I)

On the Sinai mountains, vegetation composition changes with elevation from a community dominated by *Artemisia herba-alba* between 1630 and 1700 m, to a community dominated by *Phlomis aurea* and *Pyrethrum santolinoides* between 1700 and 2000 m, and further to a community dominated by *P. santolinoides* and *Artemisia herba-alba* in the highest zone. On the northern slope of Gebel Musa, there are several tree species growing in crevices, such as *Cupressus sempervirens, Ephedra alata, Ficus carica, F. carica* var. *rupestris* and *F. pseudosycomorus* (Migahid et al., 1959).

II. Hyperarid Western Desert region

The following types of community are common to all oases of the hyperarid Western Desert of Egypt (Migahid et al., 1960):

(1) **Sand dunes:** the mobile *barkhan* dunes are sterile. More stabilized dunes are dominated by *Alhagi maurorum*. At a later stage of succession, dunes are dominated by *Tamarix* spp.

(2) **Sand plains:** Community composition in the sand plains depends on local topographic variations, salinity, stability of sand and depth of soil. In dry elevated locations, the community is dominated by *Alhagi maurorum* with *Calotropis procera* and *Hyoscyamus muticus* as common associates. A *Desmostachya bipinnata* community is found in localities with deep loose sand. Where the soil is more saline the community is dominated by *Sporobolus spicatus*.

(3) **Salt marshes:** The communities of salt-marsh ecosystems occupy locations with varying degrees of waterlogging. *Cyperus laevigatus* dominates a community in areas rich in clay and organic matter, and which are inundated during winter. Common associates in this community are *Juncus rigidus, Salicornia fruticosa* and *Typha domingensis*. In drier locations, *J. rigidus* dominates a community which includes *Aeluropus lagopoides, Alhagi maurorum, Imperata cylindrica, Juncus acutus, Salicornia fruticosa, Sporobolus spicatus* and

Tamarix nilotica as common associates. In areas where the water table is still deeper and the dark clayey soil is covered by sand, *Salicornia fruticosa* dominates a community which includes *Aeluropus lagopoides*, *Desmostachya bipinnata*, *Imperata cylindrica*, *Juncus acutus*, *J. rigidus* and *Tamarix nilotica* as common associates.

III. Arid Mediterranean Desert region

a. Sinai plains (see also Appendix I)

The most common community of the gravel desert (*hamada*) in the Sinai plains is the *Anabasis articulata* community, especially in depressions and shallow water runnels. Where the runnels are covered with coarse sand, the community becomes co-dominated by *A. articulata* and *Zilla spinosa*. Other common communities are those of *Anabasis articulata*, *Haloxylon salicornicum* and *Panicum turgidum* in localities where *hamada* is covered with shallow layers of sand, and *Aristida plumosa*[1] in depressions filled with coarse sand.

b. Gulf of Suez coastal plain

The ecosystems of the Gulf of Suez coastal plain may be differentiated into two groups: littoral salt-marsh ecosystems; and desert plain ecosystems, which occupy the midland belt between the littoral salt marsh and the range of hills and mountains.

The most abundant salt-marsh communities are those dominated by *Halocnemum strobilaceum*, *Nitraria retusa* and *Zygophyllum album*, occupying successive zones parallel to the shoreline. Other less common communities are those dominated by *Limonium pruinosum* and *Suaeda vermiculata*.

The vegetation of the desert plain exhibits a mosaic pattern and not a zonal one as noted in the salt-marsh ecosystems. The following community types are described by Kassas and Zahran (1965):

(1) Desert grassland types include the community dominated by *Hyparrhenia hirta* confined to small rills dissecting the limestone erosion surface; the community dominated by *Lasiurus hirsutus* in small runnels of drainage systems; and the communities dominated by *Panicum turgidum* and *Pennisetum dichotomum* in larger tributaries.

(2) Suffrutescent woody types include communities of *Artemisia judaica* and *Iphiona mucronata* in some tributaries of drainage systems.

(3) Suffrutescent succulent types include communities of *Zygophyllum coccineum* on alluvial deposits of limestone detritus and *Haloxylon salicornicum*[2] on deep coarse alluvial deposits.

c. Wadis

In the districts of Gebel Ataqa and the Galalas, Kassas and Zahran (1962, 1965) recognized the following communities:

(1) *Cleome droserifolia* community in the main channels of Wadi Aber and Wadi Moghra–Hadeed;

(2) *Zilla spinosa* community in the main channel of Wadi Gimal and many other wadis;

(3) *Haloxylon salicornicum* community on high terraces of the main channels of Wadi Gimal and Wadi Dib;

(4) *Retama raetam*[3] community in the deltaic part of Wadi Ramiya;

(5) *Launaea spinosa* in the main channel of Wadi Ramiya;

(6) *Iphiona mucronata* community in the upstream sector of Wadi Hagul;

(7) *Haloxylon salicornicum*, *Leptadenia pyrotechnica* and *Tamarix aphylla* communities in the middle and downstream sectors of Wadi Hagul;

(8) *Acacia raddiana* community in wadis with a bed cover of coarse rock detritus draining the eastern slopes of the Galala and Esh el Mallaha ranges;

(9) *Juncus arabicus–Imperata cylindrica* community in wadis with brackish-water springs on eastern slopes of the Galala plateaux; and

(10) *Salvadora persica* community in the mid-part of Wadi Bali.

In the wadis of the limestone plateau to the south and east of Cairo, Kassas and Imam (1954) described the successional trend of communities in ecosystems of Wadi Digla, Wadi Liblab, Wadi Hof, Wadi Rashid and Wadi Garawi:

(1) The barren rock surface is occupied by a community dominated by *Stachys aegyptiaca*. Common species are: *Asteriscus graveolens*, *Farsetia aegyptiaca*, *Gymnocarpos decandrum*, *Helianthemum kahiricum*, *Iphiona mucronata*, *Pituranthos tortuosus*, *Reaumuria hirtella* and *Zygophyllum coccineum*.

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[1]Now *Stipagrostis plumosa*.
[2]Now *Hammada elegans*.
[3]Now *Lygos raetam*.

(2) The shallow wadi beds are occupied by a community co-dominated by *Anabasis setifera* and *Zygophyllum coccineum*.

(3) The parts of wadi beds where the soil depth increases up to 50 cm are occupied by a community dominated by *Zilla spinosa*. Common species in this and the previous community are almost the same. Examples are: *Achillea fragrantissima*, *Citrullus colocynthis*, *Pennisetum dichotomum* and *Tamarix nilotica*.

(4) Where the soil depth of wadi beds becomes deeper than 50 cm, different types of grassland communities become established. *Pennisetum dichotomum* dominates the communities on calcareous silty soils, while *Desmostachya bipinnata* and *Panicum turgidum* dominate communities where the soil is a mixture of alluvial calcareous and siliceous silt and sand.

(5) Terraces which represent the type of habitat of the greatest age in the wadis are occupied by scrub community types. The dominant species is usually a woody bush: *Atriplex halimus*, *Lycium arabicum*[1], *Nitraria tridentata*[2] or *Tamarix* spp.

d. Gravel desert

The desert country between the Muqattan Hills at Cairo and the Ataqa mountains near Suez has two classes of biotope: (1) landforms representing different stages of the cycle of arid erosion including limestone plateaux, runnels, erosion pavements and *hamadas*; and (2) fluviatile deposits of sand and gravel (Kassas and Imam, 1959). Wind and water remove the softer material of these deposits, leaving an accumulation of coarser material at the surface, which eventually becomes littered with flint gravel. On the gravel hillocks the community is dominated by *Centaurea aegyptiaca*. Common associates are *Allium desertorum*, *Aristida plumosa*, *Fagonia glutinosa* and *Haloxylon salicornicum*. The most common annual species are *Centaurea pallescens*, *Mesembryanthemum forsskalei*, *Pteranthus dichotomus*, *Stipa capensis* and *Zygophyllum simplex*.

In the runnels dissecting the gravel hills, there are communities dominated by *Artemisia monosperma*, *Haloxylon salicornicum*, *Lasiurus hirsutus*, *Panicum turgidum* and *Zilla spinosa*. The most common annuals are *Aizoon canariense*, *Astragalus mareoticus*, *Ifloga spicata*, *Matthiola livida*, *Mesembryanthemum forsskalei*, *Schismus barbatus*, *Senecio desfontainei* and *Stipa capensis*.

e. Western Desert

The transition between the arid attenuated and the arid accentuated provinces of the Mediterranean Western Desert of Egypt is characterized by communities dominated by *Anabasis articulata*, *Salsola tetrandra* and *Thymelaea hirsuta* near the coastal region. Further south, the communities are dominated by *Artemisia monosperma*, *Convolvulus lanatus* and *Helianthemum lippii* (Ayyad and El-Ghoneimy, 1976). Within the northern limits of the arid accentuated province, the communities become dominated by *Moltkiopsis ciliata* (El-Ghoneimy and Tadros, 1970).

IV. Arid region with winter and summer rainfall

This region is represented by the mist oasis of Erkowit (Erkwit; 45 km to the southwest of Suakin on the Red Sea). This oasis receives a rainfall (218 mm) greater than that of the neighbouring areas of Suakin (181 mm) to the northeast and Sinkat (127 mm) to the west. Whereas Suakin represents the coastal climate with winter rainfall and Sinkat the inland plain with summer rainfall, Erkowit has the privilege of receiving both winter and summer rainfall. During winter months, the Erkowit plateau is frequently swathed in clouds, which causes considerable dew precipitation. The ecosystems of Erkowit are differentiated into five zones (Kassas, 1953a):

(1) The first zone consists of a series of hills which extend parallel to the northeast border of a steep escarpment. By virtue of its position it faces the water-laden winds and sea mists. The vegetation in this zone is formed of several layers: (a) an open tree layer represented by *Diospyros mespiliformis*; (b) a closer shrub layer dominated by *Maytenus senegalensis*; and (c) an undergrowth layer co-dominated by *Coleus barbatus* and *Kalanchoe glaucescens*. In the shrub layer, the common associate species are: *Carissa edulis*, *Dodonaea viscosa*, *Euclea schimperi*, *Phoenix* sp., *Rhus abyssinica*, *R. flexicaulis* and *Ximenia americana*. *Olea chrysophylla* is not common but suspected to have been at one time more abundant since it is particularly subject to cutting for walking sticks, etc. Characteristic species of the undergrowth are: *Cis-*

[1]Now *L. shawii*.
[2]Now *N. retusa*.

the *qoz* country supports communities of *Acacia senegal*, *Balanites aegyptiaca* and *Guiera senegalensis*. Whereas the shrubs are sparse, the grass and herb layer is well developed. The dominant grasses are *Aristida pallida*, *Cenchrus biflorus* and *Eragrostis tremula*.

Sites with shallow gravel, sometimes overlain with compact drifted sand, are occupied by communities co-dominated by *Acacia mellifera*, *A. nubica* and *Boscia senegalensis*. *Commiphora africana* becomes a co-dominant instead of *A. nubica* in sites of sandy clay soils overlying Nubian sandstone. The ground cover is generally poor and the canopy is open.

In the transitional area to the hyperarid province in the north, the arboreal vegetation is very open and composed of scattered stunted shrubs. The most common are *Capparis decidua* and *Maerua crassifolia*. Grass is abundant, forming about 80% of the ground cover; the most common is *Cenchrus biflorus* (Ramsay, 1958).

VII. Semi-arid tropical Eastern Desert region

The semi-arid communities between the Blue Nile and the Sudano-Ethiopian borders are fairly clearly marked by the change in dominant trees. Grasses often occur in separate patches, each dominated by a single species. The following community types are distinguished by Harrison and Jackson (1958):

(1) *Acacia mellifera* thornland on dark cracking clays, in which this species forms dense pure, almost impenetrable thickets. The undergrowth of grasses is greatly reduced. As the trees grow older, the canopy is broken, grasses invade, and the ecosystem becomes susceptible to fire invasions. The ecosystem then becomes dominated by fire-resistant grasses for years before recolonization by *A. mellifera*. Common associate tree species are *Boscia senegalensis*, *Cadaba glandulosa* and *C. rotundifolia*. The most abundant grasses are *Cymbopogon nervatus*, *Hyparrhenia pseudocymbaria*, *Sehima ischaemoides* and *Sorghum purpureo-sericeum*.

(2) *Acacia seyal–Balanites* savanna on dark cracking clay. Due to the low penetrability of soil to rainwater, this community is occasionally susceptible to flooding. This may cause the disappearance of trees and their replacement by open grass cover of *Setaria incrassata*. In drier parts of this formation dense belts of *Acacia mellifera* may be found, while in wetter areas *A. senegal* becomes common. The dominant grasses do not differ much from those of the *A. mellifera* thornland. Along the Blue Nile there is dense growth of *A. nilotica*.

(3) *Anogeissus–Combretum hartmannianum* savanna woodland on dark cracking clay. This community is confined to sloping grounds not far from hills. It is transitional to the more humid ecosystems of the Ethiopian highlands to the east. *Acacia seyal* may occur in belts alternating with the two dominant species. The dominant grasses are *Andropogon gayanus*, *Hyparrhenia pseudocymbaria*, *H. rufa* and *Setaria incrassata*.

The Red Sea hills near the Eritrean border have forests of almost pure *Juniperus procera*, with *Maba abyssinica*, *Olea chrysophylla* and *Pittosporum viridifolium* as common associates. The common grass is *Harpachne schimperi*.

VIII. Semi-arid tropical Western Desert region

These ecosystems cover the greater part of stabilized sand dunes of the *goz* country of Kordofan and Darfur. They are divided into three types (Harrison and Jackson, 1958):

(1) *Acacia senegal* savanna, in which this species occurs in almost pure stands over large areas. In drier parts this formation grades into the ecosystem of *A. raddiana–A. mellifera–Commiphora* sp. In depressions into which some clay has been drifted, *Adansonia nubica* and *A. digitata* are found. The dominant grasses are *Aristida pallida*, *Cenchrus biflorus* and *Eragrostis tremula*.

(2) *Combretum cordofanum–Dalbergia melanoxylon–Albizia sericocephala* savanna woodland, where the dominant and common trees are mostly non-thorny. Common associate tree species are *Commiphora pedunculata*, *Guiera senegalensis*, *Lannea humilis*, *Sclerocarya birrea*, *Terminalia brownii* and *T. laxiflora*. Common grasses are almost the same as those of the *Acacia senegal* savannah.

(3) *Terminalia laxiflora–Sclerocarya birrea–Anogeissus schimperi–Prosopis africana* savanna woodland which approach closely to sub-humid types of community to the south. *Tamarindus indica* is usually associated with the dominant trees. The dominant grasses are *Andropogon gayanus* var.

bisquamulatus, *Ctenium elegans*, *Hyparrhenia confinis*, *Loudetia hordeiformis* and *Pennisetum pedicellatum*. The dominant herb is *Blepharis* sp.

IX. Semi-arid tropical hill and montane region

Two distinct masses of hills and mountains occur in semi-arid parts of the Sudan which have characteristic vegetation of their own: (1) the groups of hills forming the Nuba Mountains; and (2) the mountain masses of Jebel Marra.

Nuba Mountains

The following zones are differentiated on the slopes of the masses of hills forming the Nuba Mountains (Harrison and Jackson, 1958):

(1) The rocky summits of hills are bare of vegetation except for a few *Ficus* individuals, as *F. glumosa* and *F. populifolia*.

(2) The rocky steep slopes of the hills have communities dominated by one or more of the following species: *Adenium honghel*, *Anogeissus schimperi*, *Boswellia papyrifera*, *Combretum hartmannianum*, *Dichrostachys glomerata*, *Lonchocarpus laxiflorus*, *Sterculia setigera*, *Stereospermum kunthianum* and *Terminalia brownii*. The common grasses are *Andropogon gayanus*, *Beckeropsis* spp., *Cymbopogon* spp., *Hyparrhenia* spp., *Loudetia* spp. and *Pennisetum pedicellatum*.

(3) The hard soils at the foot of steep slopes hold very little rain water, and are almost barren. Trees are often absent and there is only a scanty grass cover. Patches of *Sclerocarya birrea* and the gregarious *Lannea humilis* may occur. *Adansonia digitata* often occurs immediately at the foot of hills just above this hard zone. Where the soil is more permeable, the dom-palm, *Hyphaene thebaica*, is common. Grasses characteristic of this zone are annual *Aristida* spp., *Elionurus royleanus*, *Loudetia togoensis* and *Schoenefeldia gracilis* in drier locations, and *Cymbopogon proximus*, *Hyparrhenia confinis* and *Setaria pallide-fusca* in wetter locations.

(4) Dark cracking clay plains around the base of hills form a marked transitional zone, where the soil is mixed near the surface with rock fragments. The vegetation is co-dominated by *Anogeissus schimperi* and *Combretum hartmannianum*, and gradually merges into the *Acacia seyal–Balanites* savanna of the plain. Grasses are almost the same as those of the previous community.

Jebel Marra ecosystems

The zonation of vegetation on the Jebel Marra massif is skewed upwards on the west side by virtue of the heavier rainfall there (Ramsay, 1958). Three ecosystem zones are differentiated (Harrison and Jackson, 1958). Much of the upper zone (2500 m) is covered with short grassland of *Hyparrhenia multiplex* with very scattered *Olea* trees. In eroded locations *Blaeria spicata* and *Lavandula stricta* are common. In the middle zone (2000–2500 m) *Olea laperrini* is the commonest tree on mature soils, and *Acacia albida* on immature volcanic tuffs. *Ficus palmata* and *Salix safsaf* are common along watercourses. The trees are sparse, however, and most of the zone is open grassland in which *Andropogon linearis*, *Cymbopogon* sp., and *Themeda tridentata* are dominant. The lower zone — up to 2000 m — is largely cultivated. Among the cultivations, *Cordia abyssinica*, *Thespesia garkeana*, *Ficus gnaphalocarpa* and other species of *Ficus* are common. Dominant grasses are *Andropogon gayanus*, *Cymbopogon proximus*, *Heteropogon contortus* and *Hyparrhenia pseudocymbaria*.

X. Semi-Arid wadi region

Where the Jebel Marra massif — and to a smaller extent the Nuba Mountains — contribute to the catchment of rainwater, the run-off produces wadis of considerable size, which are bordered by typical fertile silty soils. On these soils, communities are co-dominated by *Acacia albida* and *Ziziphus spina-christi* in drier locations, and by *Cordia abyssinica* and *Khaya senegalensis* in wetter places. Locally common species are *Acacia sieberiana*, *Celtis integrifolia*, *Piliostigma thonningii* and *Tamarindus indica* (Harrison and Jackson, 1958). The commonest grass is *Cynodon dactylon*. The two largest wadis of Darfur are Wadi Kaja and Wadi Azum. These have belts of *Acacia albida* forest, 2 to 3 km wide. In less extensive wadis, especially in the Nuba Mountain area, *Acacia albida* is replaced by narrow belts of *Borassus aethiopum* and *Hyphaene thebaica*.

SOIL MICROBIOLOGY

Bacteria

Naguib et al. (1971a, b, c) made counts of total viable bacteria in five samples from the Siwa Oasis,

one from Tahrir Province (west of the Delta), two from Wadi Natrun, three from Faiyum, eight from the Kharga Oasis, and six from the Dakhla Oasis. These samples ranged from bare sandy soil to salt-marsh soils under *Tamarix*, or wasteland under *Alhagi maurorum* or *Arthrocnemon glaucum*. The counts were made in nutrient broth and the bacteria were all gram-positive, spore-forming rods. The strong relationship between numbers of micro-organisms in the soil and its chemical composition was clearly shown. The highly significant factors affecting the distribution of bacteria in the soils investigated were moisture, organic carbon and nitrogen contents, sulphates and sodium ion concentration; the relationship with chlorides and phosphates only just reached significance, while that with nitrates did not. A sample from newly reclaimed soil in Tahrir Province had the highest count of all, 1 163 000 cells per gram of oven-dry soil, while the lowest count was 450 cells g^{-1} in a mobile sand dune on the Kharga–Baris road. Another high count (above 1 000 000 g^{-1}) was also recorded in the soil of a dry red fallow field in Balat (Dakhla). In general, high counts were obtained in cultivated soils. High moisture levels also favour bacterial counts unless high values of salinity, chlorides and sulphates inhibit bacteria. The predominance of spore-formers is regarded as a response to the edaphic drought of the Egyptian desert in summer.

Fifty of the above isolates (out of 924) were found to be pectolytic (pectin hydrolysis — plant pathogens). These bacteria were found to be greatly affected by the content of organic carbon, sulphates, sodium ion concentration, phosphates and nitrates, whereas they were not significantly related to the content of moisture, organic nitrogen and chlorides. Results of the identifications showed that these soils had forms similar to *Bacillus cereus*, *B. coagulans*, *B. licheniformis*, *B. megaterium* and *B. subtilis*. The percentage of pectolytic bacteria was frequently very low (0–6%) but could reach 25% (Siwa) or 31% (Tahrir Province) of the total bacterial count. The highest percentage in Kharga and Dakhla Oases, however, was only 5% (Naguib et al., 1971c; Elwan et al., 1971a). These pectolytic bacteria are greatly affected by the presence of pectic substances in the soils, and flourish in their presence. Soils with low levels of indigenous pectolytic bacteria did not favour the proliferation of additional inocula. Pectolytic bacteria which produce a more active enzyme flourish better in the presence of pectic substances in their mother soils (Elwan et al., 1971b).

Fungi

Fungal counts in the same above-mentioned soil samples (number of fungi per gram of air-dry soil) varied as follows: Siwa Oasis 800 to 3000, Tahrir Province and Wadi Natrun 3000 to 6000, Faiyum 1200 to 6000, Kharga Oasis 400 to 6000, and Dakhla Oasis 1400 to 5600 (Naguib and Mouchacca, 1973). High salinity inhibits fungal activity, and hence a large number of spores accumulate. The sand-dune soil had a relatively high number (3200), indicating that fungi can develop in widely different soils: calcareous, erg, poorly evolved mineral, sand dune, and saline. The majority of the fungi isolated (94 species) belonged to the Fungi Imperfecti, with species of the genera *Aspergillus* and *Penicillium* at the top (both as regards the number of species isolated and the number of colonies per plate). Twenty-six species were isolated for the first time from Egyptian soils. It is to be noted that the number of species seems to correlate inversely with the distance from the Nile and isolation: Faiyum had 14 species, Tahrir and Wadi Natrun 28, Siwa Oasis 36, and Kharga and Dakhla Oases had 74 species together. Eight species in the total were Phycomycetes, and four Ascomycetes. *Mucor*, *Rhizopus* and *Syncephalastrum* were encountered in the northern part of the Western Desert and in cultivated soils in the southern oases and bordering the Nile Valley. The abundance of mycoflora is related to organic matter unless salinity is inhibiting. Although *Trichoderma* is more frequent in acid soils, *T. koningii* and *T. viride* were isolated. There is not yet enough information to determine whether these desert soils have a characteristic fungal flora.

Mouchacca and Joly (1969) studied the effect of pH on the growth of ten species of fungi isolated from the above-mentioned samples. Growth was a function of a fixed parameter characteristic of the species and of its systematic affinities. On the other hand, the effect of salinity (the ionic ratio Na:K) was not related to systematic position (Mouchacca et al., 1970), but rather to fundamental physiological processes at the level of the cellular semi-

permeable membrane. Excess sodium may cause, by competition at absorption sites, a lack of cellular potassium, even if potassium ions are sufficient in the external medium. This, in turn, slows down protoplasmic synthesis and eventually mycelial growth. At any rate, species of *Aspergillus* and *Penicillium* tolerated higher salinities and lower humidities than species of other genera more frequent in agricultural soils of the Nile Valley.

Mouchacca and Joly (1974) studied in detail the distribution of species of *Penicillium* in the same above-mentioned samples. This is generally homogeneous and shows only quantitative variations as a function of soil characteristics. It does not vary in relation to geographical position or to grain size. Soil reclamation does not cause floristic change; it only causes an increase in relative abundance of some species or a decrease of some other species. Old fields lose this effect rapidly with time when they are left fallow. The same detailed level of study on *Aspergillus* (Mouchacca and Joly, 1976) showed that species of this genus behave similarly, but they are slightly influenced by geographical position. Their behaviour is almost similar to that of *Penicillium* species in the southern part of the Western Desert, where drought is perennial. Slight differences in behaviour are exhibited in the northern part where soils are either reclaimed or receive winter rain. Some *Aspergillus* species are practically omnipresent, others develop preferentially in perennially dry soils and/or have a distribution positively or negatively affected by soil reclamation.

FAUNA

Interest in the fauna of the hot deserts of Egypt and the Sudan goes back to the time of Napoleon's expedition and the *Description d'Egypte*, to Rohlf's expedition, and to Schweinfurth's many travels. Several explorers later made some very important long-term studies of the distribution and ecology of desert animals of these two countries. Some important reviews include those of Bodenheimer (1957), Cloudsley-Thompson (1969a), Niethammer (1971) and Rzóska (1976).

Generally speaking, there are differences between the faunas of the two deserts on either side of the Nile. The fauna of the Eastern Desert is related in the northern part to that of Sinai, Palestine, the Arabian Peninsula, and western Asia. In the southern part, the fauna has a more clearly Mediterranean character than would be expected. The fauna of the Western Desert is also more or less Mediterranean in its northern part, immediately south of the coastal belt and including Siwa, the Qattara Depression, Wadi Natrun, and as far as the Bahariya Oasis, Faiyum and Minya. Further south, the fauna is typically Saharan and is related to the fauna of the central Sahara. This continues through the hyperarid part of the desert of northern Sudan, as far as the sixteenth parallel, where the grip of the desert relaxes and a varied and denser fauna appears, but still of a markedly xeric character; this is especially apparent in mammals (Wassif, 1976). For invertebrates, however, the limit lies more to the south. At the thirteenth parallel, there is a sharp diversion of the flora and the associated fauna both to the east and west of the Nile (Cloudsley-Thompson, 1969b).

Mammals

The mammals of the hot deserts of Egypt are now fairly well known. Osborn and Helmy (1980) have published a detailed and superbly documented monograph on the mammals of Egypt. Mammals of the transitional zone between Egypt and the Sudan were also fairly thoroughly studied by Hoogstraal et al. (1955–56) in Gebel Elba, and by Osborn and Krombein (1969) in Gebel Uweinat. The mammals of riverine Nubia can be compared with these two massifs from the distribution records given by Osborn and Helmy (1980). For the Sudan, the works of Setzer (1956) and Happold (1965, 1967, 1975) give the necessary information. The regional accounts given by Happold are of particular interest (1965 for Jebel Marra, 1967 for the Khartoum region, and 1975 for northern Sudan). Delany and Happold (1979) have provided a thorough and excellent account of the ecology of mammals in Africa, their life histories, ecophysiology and energetics, and populations, in each of the major African biotic zones, including the arid zone, which would be largely relevant to the hot deserts of Egypt and the Sudan.

According to Wassif (1976), the mammal fauna of Egypt comprises 10 to 11 Palaearctic species and has a strong African ("Ethiopian") character. This

is confirmed in the case of the Chiroptera (bats) where the index of faunistic affinity is 25 between Egypt and Europe and 45 between Egypt and Africa. The Nile is largely responsible for this link. The Sudan has about 224 species and subspecies of mammals, excluding bats, which alone comprise 51 species, or 66 in a more recent account. Of these 66 bat species, 42 are African, about 16 are common with Egypt and the Saharo-Sindian Region, whereas 8 are Palaearctic (7 of which live also in Egypt). Only one bat species is confined to the desert. Distribution maps of many species of ungulates show clearly the wide expansion of the fauna in the southern part of the desert as it merges into savanna and forest. Here again there are differences between the Eastern and Western Deserts; the eastern part harbours species rare, extinct or not recorded in Egypt, such as wild ass (*Equus asinus*), wild boar (*Sus scrofa*), Nubian ibex (*Capra ibex nubiana*), Beisa oryx (*Oryx beisa*), which merge with Soemmering's gazelle (*Gazella soemmeringi*) and the klipspringer (*Oreotragus oreotragus*) on the Ethiopian border. The western part harbours the addax (*Addax nasomaculatus*), the greater kudu (*Tragelaphus strepsiceros*), the scimitar-horned oryx (*Oryx tao*), the dama gazelle (*Gazella dama*), and the rhim or Loder's gazelle (*Gazella leptoceros*) (Dorst and Dandelot, 1970).

Desert mammals common to both Egypt and the Sudan and on both sides of the Nile include the dorcas gazelle (*Gazella dorcas*), Cape hare (*Lepus capensis*), jackal (*Canis* spp.), Rüppel's fox (*Vulpes rueppelli*), Libyan striped weasel (*Poicilictis libyca*), common genet (*Genetta genetta*), white-tailed mongoose (*Ichneumia albicauda*), striped hyaena (*Hyaena hyaena*), serval (*Felis serval*), caracal (*Lynx serval*[1]), and rock dassie (*Procavia capensis*). Some other species are more common in the Sudan and are either extremely rare or extinct in Egypt, such as the leopard (*Leo pardus*[2]), the cheetah (*Acinonyx jubatus*), the aardvark (*Orycteropus afer*) and the red-fronted gazelle (*Gazella rufifrons*).

From a strictly zoogeographical point of view, Osborn and Helmy (1980) prefer to call the desert belt of Egypt the Saharo-Sindian sub-region of the Palaearctic. Eight mammalian species (four rodents, three carnivores and *Gazella dorcas*) are Saharo-Sindian and of wide distribution in North Africa and southwest Asia. There are sixteen North African species in the Egyptian mammalian desert fauna, five of which (all rodents) penetrate into Palestine, Jordan and as far as northern Yemen, three (one of them a rodent) are also found in the Eastern Desert, and eight (five of them rodents) remain confined to the northern part of the Western Desert. On the other hand, three Saharo-Sindian species (all rodents) remain confined to Sinai and the Eastern Desert, and only one (also a rodent, *Spalax*) penetrates to the western Mediterranean coast as far as Cyrenaica. This distribution pattern shows that the Isthmic Desert (west of the Suez Canal) and the Nile Delta and Valley are not a completely impenetrable barrier, especially for rodents.

Moreover, the sub-region has sixteen desert-adapted subspecies of mixed Palaearctic, Ethiopian and Oriental origins, showing the intermediate character of this Sub-Region. Many zoogeographers have found difficulty in ascribing the Sahara to the Mediterranean or Ethiopian Region; some have drawn an inter-regional line across the Tibesti latitude, while others preferred to call it "transitional". Of the sixteen aforementioned subspecies, only four are rodents, there are two insectivores, a hyrax, a hare and eight are carnivores. Two other desert-adapted Ethiopian carnivores, the striped weasel and the zoril (*Ictonyx striatus*) were collected from Jebel Elba. Most of the carnivores have a wide distribution in Asia, southern Europe and sub-Saharan Africa, but their Asian origin and distribution is marked — for instance, the jackal, the fox, the hyaena, the Felidae, and the leopard. The caracal and the genet, and to a lesser degree the fennec (*Fennecus zerda*), seem to be true desert species that have successfully extended their range to circum-Saharan territories.

By and large, the staple food of these carnivores is the rodents. The chase is mostly nocturnal, or rather crepuscular. Bodenheimer (1957), quoting a 1936 publication by Heim de Balsac, records diurnal chase of rodents and hares by birds of prey. The staple food of rodents, in turn, is seeds and insects, especially their soft larvae, which are also eaten by carnivores. Desert snails are a source of food as well as water to many predators, such as *Acomys* (Osborn and Helmy, 1980). Bodenheimer (1957) could not confirm whether Saharan mam-

[1]Now *Felis serval*.
[2]Now *Panthera pardus*.

mals aestivate, although this could be probable for certain hedgehogs, jerboas, *Eliomys* and others, from what is known of related species elsewhere.

The rodents are in many ways the most important group of mammals in the ecosystems under discussion, and it is consequently worth considering their ecology at some length: their biogeography is discussed in a later section (pp. 185–188).

One can distinguish six major habitats in which these rodents live (Osborn and Helmy, 1980): rock and rugged country; desert; salt marshes; palm groves and vegetated well-watered areas; riverine habitats; and the Mediterranean littoral with its semi-desert steppe-like vegetation. With the exclusion of the Mediterranean littoral, the fauna associated with each of the other five habitats is as follows:

Rock: *Acomys russetus, A. cahirinus, Dipodillus dasyurus, D. henleyi, Eliomys quercinus, Jaculus j. schlueteri, Sekeetamys calurus*
Desert: *Dipodillus campestris, D. henleyi, Gerbillus gerbillus, Meriones crassus, Psammomys obesus*
Salt marsh: *Dipodillus amoenus, D. campestris, D. henleyi, Meriones libycus, Psammomys obesus*
Palm groves: *Acomys cahirinus, Dipodillus amoenus, D. campestris, D. henleyi, Gerbillus andersoni* (as far south as Faiyum), *G. pyramidum, Jaculus orientalis, Meriones crassus, M. libycus, Nesokia indica*
Riverine: *Arvicanthis niloticus*

On the other hand, Happold (1975) recognized only three of these habitats for the northern Sudan. These are, with their associated fauna, as follows:

Desert: *Euxerus erythropus, Gerbillus pyramidum, G. watersi, Jaculus jaculus* and *Meriones crassus* (near the Nile Valley)
Rock (Gebel): *Acomys cahirinus, Dipodillus campestris.*
Riverine: *Arvicanthis niloticus*

Again, Eisenberg (1975) recognized three ecological niches for the rodent fauna of Gaza: rock, sand and "soil". The species in each niche are:

Rock: *Gerbillus dasyurus*[1], *Sekeetamys calurus*
Sand: *Gerbillus gerbillus* (sand dunes), *Jaculus jaculus*
Soil: *Gerbillus nanus* (saline flats), *Meriones crassus*

The two most abundant species in the deserts of northern Sudan are *Jaculus jaculus* and *Gerbillus pyramidum*, which are compared by Happold (1975). *J. jaculus* makes its burrows on sandy ridges, or any land that is slightly higher than the surrounding plains, while the burrows of *G. pyramidum* are usually among the dense growth of *Capparis* and *Acacia* bushes where drifting sand accumulates in small mounds due to the dense growth of branches, which is partly a result of browsing by goats. Both *Jaculus* and *Gerbillus* are nocturnal. The former moves well away from the burrow, tends to be solitary and escapes from enemies by running rather than by disappearing into a burrow. The latter tends to remain near its burrow, to forage in groups, and to hide under cover or in a burrow. It makes large food stores, and can eat hard seeds and other seeds not eaten by *Jaculus*, such as *Acacia* seeds (Osborn and Helmy, 1980) — an important difference. Both species plug the entrance to their burrows with sand. *Jaculus* has a breeding period from October to November (sometimes to February) and its young appear to forage on their own when they are one-half to two-thirds of adult weight. On the other hand, *Gerbillus* has a longer breeding period from June to February/March, and its young forage when they are only one-fifth to one-quarter of adult weight. The ability of *Gerbillus* to store food and to eat hard seeds and seeds not eaten by *Jaculus* may explain its longer breeding period and the shorter maturation time of the young. Although *Gerbillus* forages far from its burrows, the burrows are made near shrubs where windblown grasses and seeds accumulate. It appears then that *Gerbillus* is more efficient in exploiting its habitat resources, provided shrubs are available to facilitate accumulation of these resources. Overgrazing by goats may enhance their chances to utilize such resources. *Jaculus*, on the other hand, is able to exploit resources of treeless and much poorer country by foraging far and wide away from the burrows, and in this sense may be considered better adapted to scarce food resources, at the price of a limited breeding period and a longer maturation time for the young. Near gebels, such as in the Sabaloka Gorge (Fig. 5.4), both species remain in the sandy semi-desert at the base of the hills, although the gebels have a more diverse flora due to protection from a too-selective grazing by goats and camels, including such species as *Abutilon farinosum, Blepharis edulis, Cenchrus ciliaris, Cleome scaposa, Dicoma tomentosa, Forsskaolea*

[1]Now *Dipodillus dasyurus.*

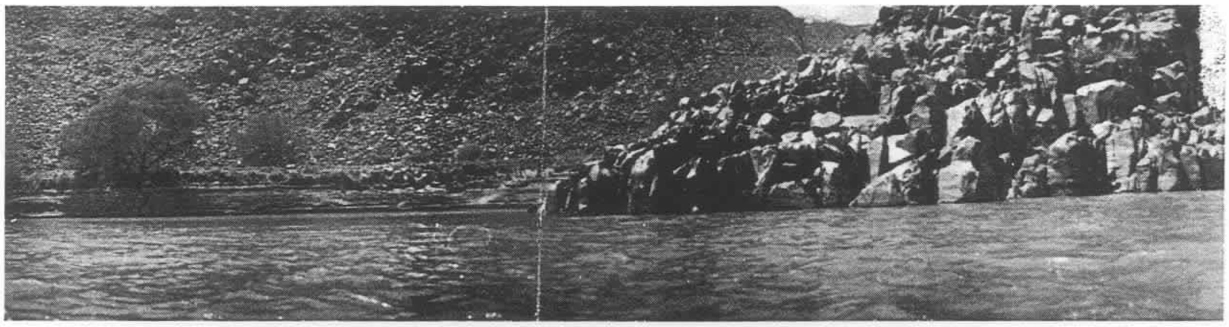


Fig. 5.4. The Sabaloka Gorge (Sixth Cataract), north of Khartoum (photo S. Ghabbour).

tenacissima, Gossypium anomalum, Heliotropium strigosum, Hibiscus micranthus and *Seddera latifolia* on Jebel Merkhiyat near Khartoum (Cloudsley-Thompson, 1968). The failure of these two rodents to exploit this extra seed source on gebels points out their fidelity to the sandy desert habitat.

The question of which of the two is better adapted to desert conditions, however, can be resolved from the above discussion. Happold (1975) considered *Gerbillus pyramidum* the better adapted because it hoards food and loses only 5% of its weight when kept on a diet of dry barley, against 34% for *J. jaculus*[1]. Osborn and Helmy (1980) questioned this conclusion because *G. pyramidum* is never found in isolated, barren desert situations where *J. jaculus* survives. Therefore, the description of *J. jaculus* as "opportunistic" by Happold (1975) seems inappropriate, because this term has come to mean desert species which frequent palm groves and vegetated areas (see discussion on birds) and not those which venture into more barren desert. Since neither rodent frequents gebels, one may regard their behavioural and biological differences as an example of niche separation and sharply delineated allocation of resources to avoid competition in an extremely poor environment. The penetration of *J. jaculus* into sandy plains without plant cover as a survival strategy obliges them to run to escape enemies — let alone the necessity to forage for long distances; and this puts a high energy cost on them, which makes the reproduction share of energy input smaller than in *Gerbillus*.

Gebel species in the Sudan, *Acomys cahirinus* and *Gerbillus campestris*, are nocturnal. The former outnumber the latter in traps, in the two gebels where the latter was discovered, by a ratio of 5:1. *Acomys* is the only species in most desert gebels and is found in dense populations (Happold, 1975). On Gebel Elba, population density was not affected by altitude (Hoogstraal et al., 1955–56), but the species was very rare on Jebel Marra (Happold, 1965). In the northern Sudan, these animals do not leave the gebels, but they were found in gerbil burrows in the broad grassy valley on Gebel Elba, and away from rocks. They also sometimes invade huts of inhabitants of the Eastern Desert. They were seen by day-time in Gebel Elba, but were most active in early morning and late afternoon. South of the Khartoum region, in the *Acacia* savanna, *Acomys* is found where fallen trees and dead grass occur around the bases of gebels. In this habitat, the species is associated with the riverine *Arvicanthis niloticus* (Happold, 1975). This is probably how they both reached Jebel Marra. Osborn and Helmy (1980) suggested that *Acomys* living in barren cliffs lacking plants probably forages for wind-blown plant litter trapped in crevices. The animals may also scavenge bat droppings, and eat insects (especially locusts) and snails if available. They are unable to subsist on a diet of dry food alone, and have a high evaporative water loss, which is probably compensated for by water obtained from eating small desert invertebrates (Shkolnik and Borut, 1969).

Arvicanthis niloticus and *Mastomys natalensis* are the two field rats of economic importance in the Sudan (Venkatraman and Badawi, 1969). The main crops attacked are sorghum, maize, wheat, *Pennisetum*, groundnuts, sesame, beans, tomato and various fruits, as well as cotton. There was a large outbreak of *Mastomys* in the 1961–62 season

[1] *G. gerbillus* gained 10%.

in the Manaqil area of the Gezira Scheme. This was attributed to the construction of irrigation canals, clearance of trees and vegetation and other agricultural practices. A high mortality of snakes and birds of prey was sometimes observed after widespread use of powerful insecticides like endrin (Venkatraman and Badawi, 1969). Hassan and Hegazy (1968) considered *Arvicanthis niloticus* an important rodent pest for agriculture (it used to be eaten as a delicacy in Upper Egypt), because its natural enemies, snakes and mongooses, had been killed off by man. Newly settled Nubians in Kom Ombo attributed the attacks of *A. niloticus* on maize to the disappearance of owls. It reportedly damages 30% of the sugarcane in Upper Egypt. *Acomys cahirinus* is also suspected of attacking crops and food stores (Osborn and Helmy, 1980). Hoogstraal (1963) remarked that farmers complained of damage to maize, barley and vegetables by *Nesokia indica*. *Jaculus jaculus* may cause some loss to Bedouins by feeding on sprouting barley and grain, and one specimen was found from a ground-nut field (Osborn and Helmy, 1980), but Hoogstraal (1963) had observed that it never invaded established crops.

A recent survey on rodent pests in Egypt (Ali, 1977) revealed that, apart from *Rattus* and *Mus*, *Acomys* and *Nesokia* may be considered pests on the fringes of cultivation in Minya and Asyut. Further into the desert, *Gerbillus gerbillus, G. pyramidum, Jaculus jaculus* and *Meriones* may be found, but their pest status was not definitely established. *Acomys* was found, in laboratory experiments, to consume daily 9.6%, 7.2% and 6.3% of its weight of crushed maize, wheat and barley respectively. These figures were three times higher than those for *Rattus* and *Arvicanthis* for the same seeds, but *Arvicanthis* consumed 12.2% of its weight of millet. Ali (1977) estimated that rodent damage to sugarcane was 30%, and that damage by *Arvicanthis* to cotton was from 5 to 26% and to wheat from 1 to 4%.

Osborn and Helmy (1978) assessed trends in population sizes of Egyptian mammals. They recognized that most rodents were not in danger of extinction. *Meriones sacramenti* and *M. tristrami* are of unknown status; *Dipodillus mackillingi* and *Hystrix cristatus* are rare (the latter may be extinct); *Arvicanthis niloticus* is expanding; whereas *Allactaga tetradactyla, Jaculus orientalis, Nesokia indica, Psammomys obesus* and *Spalax ehrenbergi* are threatened in areas of desert land reclamation.

Birds

Rzóska (1976) analysed the data of Meinertzhagen (1930) on Egyptian birds and found that sixteen species are recorded from the desert and twelve from the oases and Upper Egypt. Almost all desert birds of Egypt are Palaearctic, with affinities to the Maghreb, Sinai and Arabia (Moreau, 1966). The affinities of the typical desert species of the Sahara as a whole, whose range extends through the Saharo-Sindian subtropical desert belt, are not convincingly either Palaearctic or Ethiopian. A few reach Somalia along the Red Sea coast but not through the Sudan. Two species, the partridge *Ammoperdix heyi* and the chat *Oenanthe monacha*, do not extend west of the Nile, for they seem to need barren rocky hills which are rare in the Western Desert. The desert bird fauna is a rather specialized group with mixed origins. The Neolithic amelioration in rainfall excluded desert species from the highlands and confined them to the plains, from which they emerged to repopulate the highlands in the last 5000 years. This explains the absence of subspeciation. In the bustard and three chats, however, different subspecies are recognized east and west of the Nile, due to different foci of repopulation rather than to the functioning of the Nile Valley as a barrier (Moreau, 1966). The aridity of the post-Neolithic has caused a polarization of Palaearctic and Ethiopian species towards the Mediterranean and the southern edge of the Sahara, with a thinning out of each group in the alien habitats. The desert species could, on the other hand, spread from their refugia (Moreau, 1966). Ninety species could be recognized in the fauna of ancient Egypt, representing a richer and more African fauna, but reduced to its present condition by the impoverishment of vegetation. Faiyum is richer; the oases each have only four resident species at most.

Moreau (1966) noted three species that come to the Egyptian oases in summer in considerable numbers to breed: the turtle dove (*Streptopelia turtur*), the rufous "warbler" (*Erythropygia galactotes*) and the olivaceous warbler (*Hippolais pallida*). It is astonishing that aerial-feeding birds are absent from these oases. There are no swifts, fly-

catchers (though present on the coast), hirundines or nightjars, while the accumulation of breeding doves (two or three species per oasis), whose food relations have not been worked out, is remarkable. Moreau (1966) recommends therefore a re-examination of the ornithology of Egyptian oases after the changes induced by recent developments.

Moreau (1966) recognized 497 bird species in the Sudan, with 34 only in the arid north. The bulk of the bird fauna is concentrated south of 16°N and increases with increasing rainfall, and in accordance with vegetational belts. The region from Korosko to Khartoum is called by Chapin (1932) the Sudanese Arid District and from Khartoum to the southern border the Sudanese Savanna District, both within the Sudanese Province. Opportunities for bird life are narrowed to the thin line of the Nile stream, along which elements of the Upper Egyptian fauna merge with that of the Sudan (Rzóska, 1976) — a situation similar to that obtaining for weeds. In the Nubia Nile reaches, the encroachment of desert species on the banks is quite obvious and the riverine species experience a bottle-neck situation which reduces their numbers (Pettet et al., 1964). In the arid north, the desert and riverine faunas are sharply distinct from each other and each extends its range to the other's realm seasonally. The sacred ibis (*Threskiornis aethiopicus*) in the Khartoum region ventures into the desert in the rainy season, while desert species approach the Nile in the dry season to benefit from the water source and to exploit richer and more varied food resources, as well as to roost in large numbers. An example is the Sudan golden sparrow (*Auripasser lutens*) (Wilson, 1948). A remarkable desert bird which approaches the Nile is the sand grouse *Pterocles senegallus*, which comes in great numbers to the river in the morning. They have exceptionally well-developed powers of flight, enabling them to fly 30 to 50 km to reach the indispensable water source. Cade and Maclean (1967) confirmed that the male travels up to 30 km carrying water in its breast feathers to damp the eggs and soil around the nest, and later for the hatched chicks to drink. Whereas sand grouse, larks and coursers nest and feed in the desert, only flying to water to drink, the majority of resident species actually inhabit the fringe of deserts and never go far from water sources. Most of the birds to be seen in deserts are migrants or birds of passage which leave the desert area when conditions become unfavourable (Cloudsley-Thompson, 1969b). In the southern part of the Sudanese Savanna District, the distinction between riverine and extra-riverine faunas becomes less and less obvious as rainfall increases, so that birds have ranges extending across Darfur, Kordofan, Gezira and Kassala in one continuous belt.

Moreau (1966) distinguished among desert birds between opportunists that can penetrate into mesic habitats and typical desert species restricted to xeric habitats. The former adapt to the vegetated environment within the oases, such as the chat *Oenanthe leucopygia* which frequents houses in Siwa and Dakhla Oases, and cemeteries in Bahariya Oasis. Certain birds of prey, such as *Bubo bubo*, have penetrated the Sahara thoroughly, though normally inhabiting well-vegetated country. Lanner falcons (*Falco biarmicus*) and peregrines (*F. peregrinus*), which are not typically desert birds, have been found breeding on fragmentary outcrops of rock in full desert, even in the Great Sand Sea. It is believed that they depend entirely on spring migrants and depart after breeding, since they alternate with another species, *F. concolor*, which is a specialist confined to the Sahara, capable of breeding in the hottest season (August) and in the utmost extremity of desolation. Lanners breed in spring and were found in the same areas as constitute the *F. concolor* breeding grounds in August (in the area of Kufrah Oasis, Libya), suggesting an alternation of these two species in exploiting migrants. The extraordinary August breeding season of *F. concolor* is apparently adapted to take advantage of the temporarily abundant food supply of autumn migrants caught at dawn and dusk (Moreau, 1966). The ostrich, surviving in the southern and eastern fringes of the Sudan desert and long extinct from Egypt (though seen lately at Gebel Elba) is also a typical desert species with its own adaptations, approaching those of the camel (Cloudsley-Thompson, 1969b). Ostriches occur where some water or succulent food is available, and migrate in summer (rainy season) to places where succulent food is abundant, even if water is not available in the immediate neighbourhood (Cloudsley-Thompson, 1969b). In oases and in Jebel Marra, where water is perennial, they feed on non-succulents, such as *Trichodesma*, locally known as *shok-el-naam*, or ostrich thorn.

Some birds have adapted radically to human land-use practices, superimposed on climatic vicissitudes. To start with a simple example, telegraph poles along railway lines have provided nice perching positions in the treeless and featureless flat deserts of the northern Sudan. Apparently, territoriality and allocation systems for these perching positions are established among individual birds, as is the case for the Egyptian vulture *Neophron percnopterus* in the northern Abu Hamed area and the bee-eater in the Obeid plains. These perching positions attract exceptionally large numbers, and undoubtedly have a positive effect on feeding and breeding opportunities of bird species that use them.

There are about nineteen bird species known as crop pests in the Sudan, as far south as the ninth parallel, most of them being weavers between 12° and 16°N. Only a few of them cause serious damage, but many may cause notable damage in some localities, such as the Sudan dioch (*Quelea q. aethiopica*). Its nesting area in 1947 in the eastern Sudan extended from Gedaref to Khashm el Girba. Due to the poor rains of that season, nesting took place in general further south than in 1946, and also about eighteen days later (Wilson, 1948). The Sudan house sparrow (*Passer domesticus arboreus*) is widespread throughout the arid part, where it occurs in the vicinity of human habitation. It stays awake for several hours after sunset, foraging for spiders on walls of buildings in the illuminated streets of Khartoum and Wad Medani (Ghabbour, 1972a). The turtle dove (*Streptopelia senegalensis aegyptiaca*) is fast becoming a pest in cultivated desert areas of Egypt (Ghabbour, 1976b). *Pterocles* has increased to a quasi-pest status in the Nubia Nile region. Among migrants the golden oriole (*Oriolus o. oriolus*) attacks maturing dates in Bahariya Oasis in September, but it is welcome as a game bird by the inhabitants (Ghabbour, 1972a). The Spanish sparrow (*Passer hispaniolensis*) attacks grain crops in the Dongola region (Wilson, 1948).

Hunting pressure in Egypt is mainly directed towards waterfowl (Meininger et al., 1979; Brown, 1981). Among desert birds, the ostrich disappeared because of hunting and collection of eggs; the bustard is systematically hunted by and for western Asians. The desert partridge is hunted by the two hundred members of the Cairo Shooting Club when the duck season is over (Brown, 1981). Peregrine falcons are captured alive everywhere they are known to nest, and are sold to western Asians at 5000 Egyptian pounds for the yearling female. In the central Sudan, it is expected that park-land savanna birds (tree-nesting) will be gradually replaced by deserticolous species (ground-nesting) as the tree cover is removed and the desertification proceeds.

Reptiles

The most recent surveys of the reptilian fauna of Egypt are those of Kamal et al. (1966a, b) and Marx (1968). Very little is known on reptiles of the Sudan at the same level of detail, although regional faunas of the Khartoum district exist.

The Egyptian herpetofauna comprises some 93 species, with the highest affinity exhibited towards southwestern Asia, western North Africa, and Red Sea coastal regions (Eritrea, Ethiopia, Somalia) in descending order. The percentage of Egyptian fauna occurring in these regions is 68, 40 and 37 respectively (Marx, 1968). Next in order of affinity is East Africa with 27% of Egyptian species occurring there. Four species are endemic to Egypt. Three of them are in Sinai: *Coluber sinai*, *Telescopus hoogstraali* and *Uromastix ornatus*. The fourth is from Gebel Elba: *Ophisops elbaensis*, a lizard.

The number of species decreases from north to south and from east to west (Table 5.5). The higher number of species in Faiyum is obviously the result of its proximity to the irrigated lands of the Nile Valley and Delta. The northwestern Mediterranean coast, for comparison, has nineteen species of lizards and fifteen of snakes, although it is not

TABLE 5.5

Number of species of lizards and snakes in different regions of Egypt (based on data of Marx, 1968)

District	Lizards	Snakes	Total
Sinai	13	13	26
Eastern Desert (northern part)	19	11	30
Eastern Desert (southern part)	11	6	17
Gebel Elba	12	7	19
Wadi Natrun	14	7	21
Siwa Oasis	7	5	12
El Maghra Oasis	3	2	5
Faiyum	16	8	24

irrigated and is ecologically a semi-desert. However, it is also much more vegetated and the vegetation is more evenly distributed over much larger areas than in the inland rainless deserts.

Application of Sørensen's coefficient of similarity to the data presented by Marx (1968) indicates that the strongest inter-regional affinities occur between the northwestern coastal zone on the one hand and Wadi Natrun, Faiyum Oasis and the Nile Valley on the other hand, and among these latter three (coefficients above 65%). This indicates strong Mediterranean affinities. However, Siwa Oasis has a weak similarity with the northwestern coastal zone (48%) and stronger affinities with Wadi Natrun and the Nile Valley (50–65%), indicating a more truly desert fauna in the former and a mixed fauna in the latter two. The northern part of the Eastern Desert, which seems to have served as a gate with southwestern Asia, has strong affinities with all other regions (50–65%), except with Sinai (45%) — a somewhat surprising figure — and Gebel Elba (30%). The latter region has a strong affinity naturally with the southern part of the Eastern Desert (59%) and a weaker affinity with the Nile Valley (45%), and bears almost no resemblance to other regions as far as its herpetofauna is concerned (27% with Sinai). This is completely in disagreement with the affinities of its moss flora which is predominantly of Mediterranean affinities. This also applies to the region of Nubia (Imam and Ghabbour, 1972).

Invertebrates in general

Rzóska (1976) pointed out that invertebrate groups in Egypt and the Sudan have attracted more attention than the flora and the vertebrates, but what has been done reflects the dry character of the area, especially in a number of insect groups. The presence of the Nile in the middle of the area is an important characteristic that must be referred to. There is a severe selection of groups and species fit to live under desert conditions.

Rain-pool fauna

One may begin with a peculiar group of invertebrates which takes advantage of the temporary rain pools formed after summer rains in the Sudan, which may last from a few days to three or four months, to develop and finish their life-cycles in this brief period. Their rapid development from drought-resistant eggs or stages to full maturity in a few days, tolerating high temperatures (up to 80°C), is remarkable (Rzóska, 1961, 1976). This particular fauna is mostly crustacean, with a few rotifers. The main species are *Triops* spp. (which mature in seven days), *Moina* (five days) and *Metacyclops* (two days only). The eggs of *Triops* have a lethal temperature a little below boiling point, while a high temperature is necessary to break their diapause (Carlisle, 1968). Cloudsley-Thompson (1968) discussed his findings of the adaptive temperature tolerance and responses to light and mechanical stimuli of *Triops*.

Apart from Crustacea, a number of insects — water beetles, bugs and mosquito larvae — develop in the rain pools. A few adult *Anopheles gambiae* survive throughout the dry (winter) season in partial diapause. They take frequent, but incomplete, blood meals which result in the failure of ovarian development, before diapause, which is triggered by lower temperature and lower humidity. The ovaries develop extremely slowly so that, when the rains come, the gravid females are ready to oviposit in the temporary rain pools as soon as they appear (Omer and Cloudsley-Thompson, 1968).

Animals that are not particularly adapted to drought, due to high evaporative water loss, may appear in large numbers on the surface of the desert after rain. An example is the conspicuous giant velvet mite (*Dinothrombium tinctorium*), which is diurnal in the wet seasons and crepuscular in the dry season. The adults may feed on termites and small insects, but the larvae are parasitic on grasshoppers and locusts (Cloudsley-Thompson, 1968).

Regional faunas

Cloudsley-Thompson gave accounts of the desert invertebrate faunas of some regions in the Sudan in a series of papers, which will be summarized below.

Cloudsley-Thompson (1964, 1968) and Cloudsley-Thompson and Idris (1964a) described the invertebrate fauna of Khartoum Province and the nearby Jebel Merkhiyat. The desert fauna of Khartoum, in spite of the Nile and the *Acacia* scrub of the surrounding desert, is extremely sparse. The number of species seems to be less than

in the northern parts of the Sahara. The reason may be related to the severity of the microclimate even in the holes and retreats of nocturnal animals. A high proportion of the fauna consists of carnivorous forms, although the basis of the food chain is plant litter. The seeds of annual grasses are regularly collected by ants. On the insects — chiefly, Thysanura, beetles and locusts — depend, directly or indirectly, the remainder of the fauna (Cloudsley-Thompson, 1964). The severity of the microclimate can be gauged from the behaviour of the scorpion *Leiurus quinquestriatus*, which inhabits deep holes and closes the entrance with a plug of dead leaves (as does also the solifuge *Galeodes granti*, its predator), while in North Africa it lives in shallow scrapes underneath rocks (Cloudsley-Thompson, 1968). Ants and tenebrionids are diurnal, and so is their predator *G. granti* (Cloudsley-Thompson, 1977a). The tenebrionids *Adesmia antiqua* (diurnal), *Ocnera hispida* (diurnal) and *Pimelia grandis* (nocturnal) respond to near-lethal temperatures by digging into the sand. The "camel-spider" *Galeodes granti* and the scorpion *L. quinquestriatus* survive 50° and 48°C, respectively, for 24 h at relative humidities below 10%.

Quite a number of jumping spiders feed upon ants (e.g. *Monomorium salomonis*). The calliphorid flies *Bengalis peuhi* and *B. minor* snatch larvae and adults with their proboscis. Other spiders (e.g. some ground-living species of *Agriops* and *Nephila*) attack Thysanura, ant-lion larvae, and other insects. *Acacia* trees are the food source for the desert locust *Schistocerca gregaria*, the buprestid beetle *Sternocera castanea*, and the "bag-worm" larvae of the psychid moth *Auchmophila kordofensis*. The commonest parasitoid of these larvae is the fly *Tachina ebneri*. The horse-fly *Tabanus* attacks camels (Cloudsley-Thompson, 1968).

In Jebel Marra, Cloudsley-Thompson (1966) found earwigs (*Forcipula gariazzi*) and lycosids (wolf spiders). The spiders were active during daytime, and the earwigs were hiding beneath stones; at night the activities of the two species were reversed, and the earwigs crawled on the pebbles beneath which the wolf spiders were hiding. A termite species, *Odontotermes kibarensis*, not previously known outside Uganda, was found on Jebel Marra.

In the Nuba Mountains, southern Kordofan, Cloudsley-Thompson (1969c) collected isopods and chilopods (centipedes) near a dried watercourse. Other arthropods included scorpions, such as *Leiurus quinquestriatus*, the termites *Odontotermes smeathmani* and *Trinervitermes geminatus*, which were very common, some spiders, five praying mantids (described as belonging to an unusually rich fauna), one tettigonid, one acridid, seven hemipterans and a number of *Adesmia* spp. and other tenebrionids. While the fauna of the Jebel Merkhiyat is as poor as that of the surrounding plains, that of the Nuba Mountains is of greater richness as compared with surrounding plains. This is ascribed to the higher rainfall and consequently richer vegetation, occurring south of the thirteenth parallel.

In the Ingessana Hills, southwest of Er Roseires, the fauna was also much richer than on the surrounding plains (Cloudsley-Thompson, 1969a). Collection under rocks beside a dry watercourse provided the isopod *Periscyphis albescens*, which ranges from Cairo to the Ethiopian border at Sinja on the Blue Nile. Two large geophilid centipedes, three scorpions, some ticks and a few spiders were also collected. Ground-living insects included the termites *Macrotermes bellicosus*, *Odontotermes nilensis* and *Trinervitermes togoensis*. Ants included *Camponotus maculatus*, *Pheidole* sp., *Monomorium* sp. and a doryline. Beetles and the pyrrhocorids *Odontopus sex-punctatus* and *Dysdercus fasciatus* were also among the collections. Lighted and unlighted traps caught *Gryllulus* sp., several moths, dipterans, hemipterans, ants, staphylinids and a trichopteran. A suction trap caught the moth *Chilo zonellus*, a common pest of sorghum.

In the Dinder area, the only invertebrates mentioned by Cloudsley-Thompson (1969a) are the blood-sucking "seroot-flies" (Tabanidae) which become numerous in the wet season and force game animals to escape and flee southeastwards over the border into the foothills of Ethiopia, or migrate northwest into the Butana grasslands. It is this migration route that is threatened by the Rahad Canal from the Er Roseires Dam.

Butterflies

Although no comprehensive zoogeographical study has been done for the whole area in question, the study of Carcasson (1964) which was limited to the Ethiopian region, starting at the latitude of Khartoum, will be illustrative. The natural biogeo-

graphic classification is based on habitat rather than on semi-arbitrary geographic barriers. The whole area south of Khartoum to the Ethiopian and Uganda borders is part of the "Sudanese Zone" of the "Northern Division". It also includes the Red Sea mountains of Sudan to Gebel Elba and the Kapoeta Desert of southern Sudan to Lake Rudolf (Turkana). This is an area of overlap with the "Somali Zone". The Division has 170 species of which 107 are Lycaenidae, 17 Pieridae, 16 Hespercidae, 12 Acraeidae, and 7 Satyridae. The Sudanese Zone is less rich than the Somalia Zone, which derives many species from East Africa and the Zambesian Zone, and from the Oriental Region. The narrow belt of *Isoberlinia* woodland separating the open formation of the north from the northern margin of the equatorial forest has a butterfly fauna the bulk of which is made up of a mixture of xerophilous species and marginal forest species, with also some endemic species. A comprehensive list of typical species of the zone is given by Carcasson (1964).

Dragonflies

Although dragonflies are aquatic or hydrochorous insects, they are a conspicuous and an ecologically important component of the fauna of water bodies within deserts. Dumont (1980) gave recently a review of the dragonfly fauna of Egypt and the Sudan. The Nile drives an "Ethiopian" wedge between the Maghrebian and Levantine "Palaearctic" domains. Few dragonflies actually breed in the Nile itself, but rather in its marginal standing or near-standing waters. Egypt has no endemic species. However, a small but significant fraction of its fauna is restricted to the North East African Province of the Tropical African Sub-Region. The dominance of Ethiopian species is almost absolute; Palaearctic and Oriental influences are limited to the presence of eight meso-Asiatic and four circum-Mediterranean species. The role of the Nile as a barrier is illustrated by the *Ischnura elegans* group. *I. saharensis* occurs west of the Nile Valley, Tripolitania, Fezzan and Waw an Namus, *I. senegalensis* occurs in Giarabub, all over Egypt and Sinai, and reaches the Dead Sea. Happold (1966) found it on Jebel Marra. *Pseudagrion kersteni* is a rather typical forest species from the Sudan which does not occur in Egypt (Dumont, 1973), although it could follow Nilotic gallery forests. Other *Pseudagrion* species occurring in Egypt have a wide Saharan distribution but do not occur in Sinai, and are replaced in Israel by a different group which arrived through the Rift Valley (Dumont, 1973). Another different case is *Agriocnemis sania* which occurs in Israel, Sinai and the Ghat Oasis (Libya) and represents a relict of an invasion from Asia into North Africa across the Nile Delta (Dumont, 1974), or perhaps before its formation.

Termites

The termite fauna of the Sudan is predominantly that of the southern edge of the Sahara, while elements of the East African fauna may exist in the southeastern corner of the country (Harris, 1968). *Psammotermes hybostoma*, the sand termite, inhabits the fringes of the Sahara and Nubian deserts and their oases, whenever the sandy soil supports some vegetation. It feeds on wood, vegetable debris and dung, and on living plants, including the poisonous shrub *Calotropis*. Cloudsley-Thompson and Idris (1964a) found them under stones and refuse, and in sand tunnels on *Panicum turgidum*, or mostly under animal droppings, presumably benefiting from greater moisture and food availability. The range of *Psammotermes hybostoma* extends from Faiyum and Minya in Egypt, including the Farafra, Dakhla and Kharga Oases (Hussein, 1980), to Khartoum, Port Sudan and Tokar, according to Harris (1968), who merged this species with *P. assuanensis* and *P. fuscofemoralis*. However Hussein (1980) believed the three species to be distinct in morphometric measurements and to have well-defined different habitat and food preferences. *P. assuanensis* is always confined to houses, while the other two only attack dead trees and timber in fields. *P. fuscofemoralis* attacks dead parts of trees and stumps, and *P. hybostoma* attacks cut palm fronds and their stumps in orchards. The merged records of *P. hybostoma* given by Harris (1968) are associated with either wood or crops.

Another species, of more Mediterranean affinities, is *Anacanthotermes ochraceus*; these harvester termites, associated with clayey soils and some vegetation, have subterranean nests sometimes at considerable depth. Workers carry dry grass and vegetable debris back to the nests. Soft timbers (employed in rural buildings) are eaten. Mudbrick buildings collapse as a result of extensive tunneling

to seek out the straw used in the clay mix, while grass and palm thatches are also eaten. This species occurs in Egypt in the Siwa Oasis, the eastern Delta and the Suez Canal Zone, and it extends southwards to Minya and Faiyum where it co-exists with *Psammotermes hybostoma* (Hussein, 1980). In the Sudan, it was reported only from Port Sudan (Harris, 1968). The other termite of importance occurring in Egypt is *Amitermes desertorum* in the southern oases (Hussein, 1980).

According to the distribution records given by Harris (1968), a riverine fauna exists in the northern Sudan, adapted to a dry atmosphere, sandy soil and permanent water. Some species of this fauna do not extend to the Gezira. Others occur in the north, but extend along the White Nile to Malakal, or even to Mongalla or the Blue Nile, or both. The other fauna is extra-riverine, rain-dependent and extends across the Gezira and even to the north of Khartoum. The Nuba Mountains have a fauna richer than the surrounding plains and Jebel Marra has a fauna different from that of the Nuba Mountains, showing affinities with the fauna of West and Central Africa — for instance *Pseudacanthotermes spiniger*. The commonest species in the semi-arid Sudan is *Odontotermes nilensis*, which has underground nests with fungus gardens.

Losses of crops due to termites may be considerable on occasion. Losses of groundnuts were estimated as 25% at Abu Hamed in the 1956–1957 season, while at Dongola the 1959 crop was a failure due to termites. They may damage cotton in the Gezira, and some damage to cotton and groundnuts is caused at Tozi (Harris, 1968).

Oligochaetes

Members of this group, earthworms and their aquatic allies, are typically excluded from deserts because of their high water requirements and high rates of evaporative water loss (Ghabbour, 1975d). The present distribution of oligochaetes in the oases of the deserts of Egypt and the Sudan (Khalaf El-Duweini and Ghabbour, 1968a, b) shows that their species have originated from invasions or introductions of extra-Saharan provenance, either from the Maghreb or from the Ethiopian region. *Gordiodrilus siwaensis*, an endemic, occurs in the Siwa Oasis, while *G. zanzibaricus* occurs in the Selima Oasis. The closely related *Nannodrilus staudei* occurs in Beheira and in the Baris Oasis in the Kharga Oasis Depression. The Siwa Oasis harbours other species which are predominantly Ethiopian, particularly from southern Sudan and Kenya, indicating former pluvial periods of at least 500 mm rainfall along the coast. The Siwa Oasis also harbours one Palaearctic lumbricid, *Eisenia rosea*, which is closely related to a form in Sardinia, indicating a North African route. Only one species has been able to cross the Sinai: *Allolobophora jassyensis*, but it has remained confined to the Delta. Thus, the Nile prevented an overlap of "Maghrebian" and "Levantine" faunas. An aquatic species, *Alma nilotica*, occurs in the Bahariya Oasis, denoting with other pieces of evidence a former connexion with the Nile. A few species of the Oriental genus *Pheretima* are established in the Nile Delta and Valley in Egypt, but only *P. elongata* occurs in the Sudan in the Nile Valley and Jebel Marra (Ghabbour, 1976a).

Earthworms constitute an important component of the food of some wildlife species in western Sudan. For example, they may be the staple food of the dik-dik, one of the smallest antelopes, in Jebel Marra. The dik-dik is usually a browser, but also digs for roots and tubers. It seems to have developed the habit of digging for earthworms instead in the Jebel Marra forests. This may be a unique example of a carnivorous antelope. For this reason it is not hunted by the local population. At the southern fringe of the Sahara, at Buram south of Nyala, baboons dig the moist soil around *rahads* (large seasonal rain pools) looking for earthworms to serve as food.

Effect of protection from grazing on insect fauna

The only work known to us dealing with the effect of protection from grazing on the insect fauna, in the hot deserts of Egypt and the Sudan, is the one by Cloudsley-Thompson and Idris (1964b), carried out near Khartoum for more than two years. It appears that the size of the total fauna is not markedly greater in the ungrazed plot than in the freely grazed area outside. In both areas, the fauna was richest during the rainy season. In fact, some groups are more numerous in the grazed than in the protected plot — for instance, ants (*Monomorium salomonis*), Thysanura, and some Tenebrionidae. Groups that were more numerous in the

protected plot were Isoptera (termites — *Psammotermes hybostoma*) and Neuroptera (ant lions). Larvae of Lepidoptera (hawkmoths — Sphingidae) were seen moving in large swarms towards the protected plot at the end of August. On the other hand, the beetle *Merosiena angustata* had its main annual peak in the grazed area in December–February, while none were found in the protected plot during that season. Because the plot, which belonged to the semi-arid *Acacia* scrub zone and had been fenced for several years, did not show large differences in insect fauna from the freely grazed area, it was concluded that the wet–dry seasonal cycle is more effective in controlling the number of animals in that area than protection from grazing. However, the slight differences observed in the numbers of some groups may be due to changes of food availability and cover provided by the dense growth of grasses. This was confirmed by the much greater number collected in both areas in the 1961 season with an unusually high rainfall. Insect populations on the Erkowit Plateau south-east of Sinkat were also found to be closely related to precipitation (Cloudsley-Thompson, 1952).

BIOGEOGRAPHY

Plant origins and distribution

Studies in a number of different fields have shown that the positions of climatic boundaries shifted violently over a long time period of the Late Quaternary in low as well as high latitudes. Three periods of different levels of biological activity can be distinguished in the last 20 000 years: a period of low activity, a period of high activity and a third of reduced activity (Grove, 1977).

At the height of the last glacial period (20 000–13 000 years ago) global biological activity and terrestrial biomass were at low levels. In general, the inter-tropical regions were drier than at present (Williams, 1975), active dunes occupied much of the Sudan (Grove, 1973), and arid conditions extended into semi-arid regions. After 15 000 years B.P. global climatic conditions ameliorated. By 9500 B.P., the basins in tropical Africa held extensive lakes where the annual precipitation seems to have been about 150% of present-day means. Semi-arid conditions in Africa were limited to certain western coastal strips in low latitudes and to regions that are now arid. The present semi-arid regions were much better watered than they are today. About 7000 years ago the climatic conditions began to deteriorate, and after 5000 B.P. it became markedly drier in tropical Africa. These climatic changes of the last 20 000 years are only the latest in a Quaternary history of more than a million years, but are important because of the deep impression they have made on arid and semi-arid lands in general (Grove, 1977).

During the Pleistocene, Egypt experienced a series of pluvial episodes during which the Nile and its tributaries were able to transport great masses of gravels and sands eroded from desert hills. Soils which have developed on these terraces suggest that there was an appreciable vegetation and considerable moisture (Butzer, 1965a). The ecological conditions outside the Nile floodplain were comparatively favourable in Neolithic and predynastic times, and also in dynastic times until the Sixth Dynasty. Culturally dated geological deposits leave no doubt as to increased discharge and rubble transport of desert streams.

In the light of pictorial evidence, which in some instances has been verified palaeobotanically, it has been suggested that the Red Sea hills formerly experienced 100 to 150 mm of rainfall annually (compared with a maximum of 20 mm today). The latitudinal shifts of the desert and grassland belts of the north and south are thought to have had an extent of 200 km on average, with a contraction of the Sahara (Butzer, 1965b). The absolute change was trivial but of great ecological significance on a local scale. Definite evidence is found on reliefs of the Fifth and Sixth Dynasties, which show characteristic, irregular low desert shrubs and succulents and perhaps alfa grass (probably *Lygeum spartum* or *Imperata cylindrica*). There was also a sparse growth of sycamore fig (*Ficus sycomorus*), *Acacia* and tamarisk, which made up an "acacia desert–grass savannah" vegetation. Another piece of evidence is the fauna of the Eastern Desert, the Nile Valley, and Dakhla area, and the highlands of the central Sahara. The rock drawings of these areas show an array of animals including elephant, giraffe, oryx, antelope, large cats, hyaena and ostrich.

A temporary worsening of conditions is indicated between the First and Fourth Dynasties,

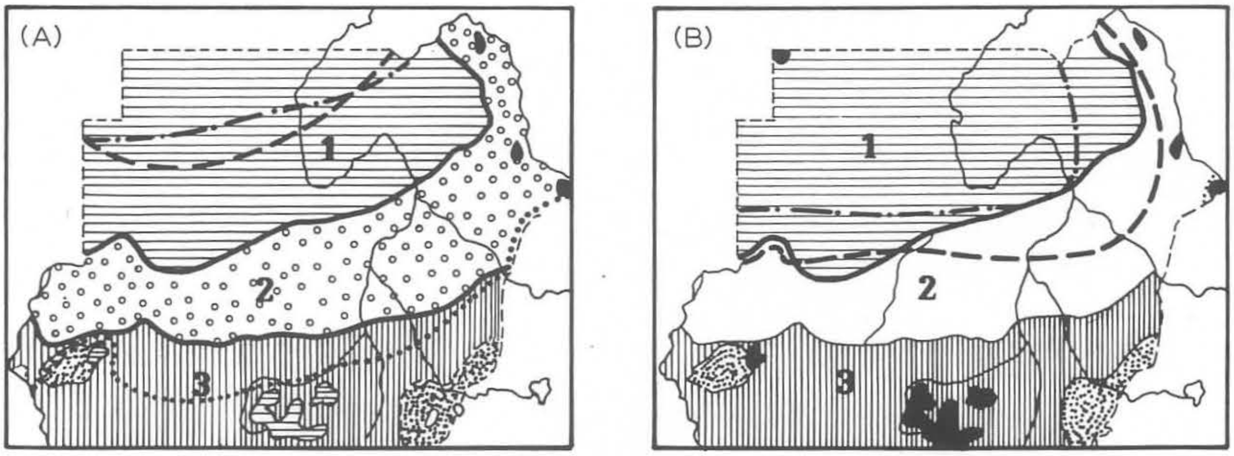
when a major faunal break took place. This culminated in the modern aridity by the time of the Sixth Dynasty, when dunes invaded the western margin of Middle Egypt. The period from 2350 to 500 B.C. was exceptionally dry, but thereafter conditions become more or less those prevailing today.

There is very little fossil evidence of the flora of the Sudan during the Pleistocene. In Darfur Province fossil impressions of *Cyperus papyrus* are reported in a crater lake, an unlikely habitat for this sedge (Colchester, 1927, as quoted by Wickens, 1975b). In Kordofan Province, fossil fragments of *Phragmites* sp. and pollen grains of Chenopodiaceae suggesting swamp conditions are recorded in an area of 200 mm annual rainfall. Fossil fruits of *Celtis integrifolia*, a riverine tree, have been reported around Khartoum where the present-day annual rainfall is 163 mm (Arkell, 1949). The present-day northern limit of that tree is approximately the 400-mm isohyet (Monod, 1964). The abundance of the sub-fossil *Limicolaria cailliaudi* at Khartoum (Arkell, 1949) supports this evidence. Depending on various pieces of evidence, Wickens (1975a) suggested that the shifting of vegetation zones in the Sudan as approximated in Fig. 5.5 had taken place since 20 000 years B.P.

The vegetation of the desert ecosystems of Egypt and Sudan today lies within the following zones of Good's phytogeographic classification system (Good, 1953): (1) northern Egypt belongs to the Mediterranean Region of the Boreal Kingdom; and (2) middle and southern Egypt and the North Sudan Desert Region, Sudanese Steppe Park Region, and the North-East African Highlands belong to the African Subkingdom of the Palaeotropical Kingdom.

According to Takhtajan's system (Takhtajan, 1969), the vegetation of these ecosystems belongs to the following zones: (1) northern Egypt belongs to the Mediterranean Region of the Tethyan Subkingdom of the Holarctic Kingdom; (2) middle and southern Egypt and the northern Sudan belong to the Saharo-Sindian Region of the African Subkingdom of the Palaeotropical Kingdom; and (3) the central Sudan belongs to the Sudano-Angolan Region of the African Subkingdom of the Palaeotropical Kingdom.

The more recent and detailed classification by Quézel (1978) locates these vegetation types in the following regions: (1) northern Egypt belongs to the Steppic East-African Domain of the East Mediterranean Subregion of the Mediterranean



1. Desert
2. Semi-desert scrub and grassland
3. Thorn savanna and scrub

——— Present
- - - - Wet period (6000–3000 B.P.)
—·— Very wet period (12 000–7000 B.P.)
.... Dry period (20 000–15 000 B.P.)

Fig. 5.5. Shifting of vegetation belts in the northern and central Sudan since 20 000 years B.P. A. Lower limit of desert region. B. Upper limit of thorn savannah and scrub region. (Adapted from Wickens, 1975a.)

Region of the Mesogean Subkingdom of the Holarctic Kingdom; (2) middle and southern Egypt and the northern Sudan — except the Red Sea coastal belt — belong to the North-East Saharan Domain of the Saharan Subregion of the Saharo-Arabian Region of the Mesogean Subkingdom of the Holarctic Kingdom; (3) the central Sudan belongs to the Southern Saharan Domain of the Saharo-African Subregion of the Sudano-Angolan Region of the Palaeotropical Kingdom; and (4) the Red Sea coastal area belongs to the Eastern Saharan Domain of the Saharo-Sudanian Complex zone.

In the Palaeocene, Egypt and Sudan seem to have experienced a climate essentially of the equatorial type, and were occupied by a "tropical rain forest". It appears that the Palaeocene flora has not played an important role in the formation of the true Mediterranean–Saharan stock (Quézel, 1978). In the Oligo-Miocene, northern Africa was essentially occupied by a "temperate rain forest" in the area of the present Sahara, and by a "subtropical woodland savanna" in the area of the present Mediterranean region, with a sclerophyllous "subtropical evergreen forest" on the mountains (Axelrod and Raven, 1978). This woodland savanna seemed already characteristic of a climate with a dry period. In tropical Africa there was the evolution of a montane flora in the region of the volcanic massifs, which has allowed some notable floristic and faunistic exchanges between northern Africa and the tropical south since the Miocene. Similarly, the appearance of considerable relief should have multiplied biotopes favourable to the expansion of a xerophytic flora of tropical origin. In the Pliocene the desert climate started to become established in the major part of the Sahara (Quézel, 1978), while in Mediterranean Africa palaeobotanical contributions demonstrate a very diversified flora.

Mediterranean, Irano-Turanian, Saharo-Arabian and African taxa are all represented in the desert ecosystems of Egypt and Sudan. They conform to climatic criteria, among which are the presence of an essentially dry summer, or constant dryness (Quézel, 1978). The distinction between the Mediterranean and Irano-Turanian elements is basically of geographical origin rather than being a result of thermal differences.

Sources of these taxa are both Eurasian and African. The Eurasian elements are composed of numerous types common to Europe, North America (Raven, 1973), and north-tropical Asia (Meusel, 1971), dating from the Cretaceous. These elements have become widespread over the Mediterranean region, and even more to the east. The xeric types appeared during cyclic dry periods which date from the middle of the Miocene, and profited from the elevation of the Mesogean mountain massifs. During the Pleistocene, the alternation of the truly arid phases with wetter phases has affected migrations of the floras. During pluvial phases Mediterranean taxa could have survived in certain localities with other elements of African origin. The existence of these fluctuations is the reason why endemism is evident in this flora.

The Saharo-Arabian flora could only have evolved following the establishment of dry phases forming true deserts (Quézel, 1958). The taxa belong mainly to the Apiaceae, Boraginaceae, Brassicaceae, Caryophyllaceae, Fabaceae, Poaceae, Resedaceae, Tamaricaceae and Zygophyllaceae. Endemism is quite important in this flora (Quézel, 1978).

The Irano-Turanian flora plays a minor role in the desert ecosystems of Egypt and Sudan — except perhaps in the Sinai Peninsula. It characterizes continental deserts and steppes with hot summers and cold winters — conditions which have prevailed at the end of glacial phases (Adam, 1969).

African elements must have occupied the desert ecosystems of Egypt and Sudan in the Palaeogene and even during a part of the Neogene. But the presence of species of, for instance, Poaceae — especially Andropogoneae — which are now present in the savannas of Africa and in certain highlands of the Sahara and the Mediterranean region, and which have not changed taxonomically over their entire area of distribution, leads to the assumption that the intermeshing of Mediterranean and African floras could have taken place during the Quaternary pluvial phases (Quézel, 1978). A large number of Saharan genera have, in fact, a north–south tropical distribution, such as *Mesembryanthemum, Pituranthos, Suaeda* and *Zygophyllum*. For a certain number of representatives of the vegetation of African origin, conditions would also have been suitable in America (e.g. the genera *Capparis, Ficus* and *Olea*). There was also

the possibility of exchange between the Cape and the Mediterranean region (Quézel, 1978). An appreciable number of taxa of African montane affinity are present on the Red Sea coast, which is related to the fact that the populations are always in contact through the Sudanese coastal mountain chains, particularly the Erkowit Plateau, with the flora of the Ethiopian Plateaux. The thorough exploration of certain mountains of the central and middle Sahara, such as Jebel Marra (Wickens, 1976b), brought to light a whole flora of African origin.

The Sinai Peninsula constitutes an interesting phytogeographic area as it forms a distinct border between the Mediterranean, Irano-Turanian and Saharo-Sindian regions (Zohary, 1944). The elements of its flora are composed of 299 Saharo-Sindian, 98 Turanian, 118 Mediterranean and 41 Sudano-Deccanian species. There are about 36 endemic species, mostly Irano-Turanian, and mostly confined to the mountain region.

Animals: the rodents as an example

Of all mammalian orders in these deserts, rodents especially lend themselves to a zoogeographic analysis, because of their variety, localization and subspeciation characteristics which indicate their efficient adaptation and plasticity — no doubt aided by their short life-cycles and high reproductive rates. The principal taxonomic level in this analysis is the subspecies. Four genera — *Acomys*, *Dipodillus*, *Gerbillus* and *Jaculus* — dominate the desert fauna, and are almost ubiquitous in these deserts. In the southern part, *Meriones* is more widespread, whereas in the southern fringe *Arvicanthis* and *Euxerus* (the ground squirrel) have a diffuse distribution pattern. Therefore, reliance on the distribution of taxa at the generic, or even the specific, level would give the impression of a homogeneous undifferentiated fauna.

It is convenient to consider first the northern part of the area from the Mediterranean coast to the latitude of Aswan as one block, and then the southern part to 12°N, including the transitional belt of Gebel Uweinat, Nubia, Gebel Elba, and Jebel Marra.

According to the distribution records of Egyptian rodents[1] given by Osborn and Helmy (1980) one may distinguish zones similar to those distinguished for reptiles. However, the principal taxonomic level for reptiles, and for birds as well, is the species, perhaps indicating a much older occupation of the desert. Another similarity with reptilian zoogeography is that northern zones have a higher number of distinct taxa than more southern zones. Sinai (including the Isthmic Desert, west of the Suez Canal) has nineteen taxonomic entities of rodents, and the western Mediterranean coast has seventeen such entities. The northern part of the Eastern Desert, by contrast, has only nine and the northern part of the Western Desert has fourteen (supported by the large oases and depressions). Further south, the southern part of the Eastern Desert harbours only five taxonomic entities, while the opposite side of the Western Desert has eight.

The rodent fauna of Egypt is predominantly a desert fauna. The Nile Valley and Delta have five taxonomic entities, four of which belong to two genera well differentiated and widespread in desert habitats: *Gerbillus* and *Acomys*. The fifth is the only typical Nilotic species of the fauna: *Arvicanthis niloticus*, which is also found in the Western Desert oases (the type species) and in Jebel Marra (*A. n. centralis*). The Nile Valley has constituted a barrier between the Eastern and Western Desert faunas, but to a much more effective degree than with reptiles, again indicating a more recent occupation by rodents. Only two subspecies are common both in Sinai (including the Isthmic Desert) and the northern oases of the Western Desert. These are *Acomys c. cahirinus* and *Nesokia indica suilla*. The former has an essentially Deltaic distribution pattern, and has spilled over both sides of the Delta to the Gulf of Suez on the east, and to Wadi Natrun and the Bahariya Oasis to the west. It is not actually found in Sinai, where it is replaced by *A.c. dimidiatus*. *Nesokia* had a much wider distribution in Egypt, to which it migrated probably via ancient riverine or deltaic habitats across northern Sinai. Thus, these two species are special cases and negate the possibility of trans-Delta interchange of rodent faunas of the Eastern and Western Deserts. A trans-Nubia Nile crossing may have enabled *Dipodillus a. amoenus* to exploit the southern part of the Eastern Desert as far as Wadi Naam, north of Jebel Elba. This nominate subspe-

[1]The genera *Rattus* and *Mus* are excluded from this discussion.

cies has an essentially Western Desert distribution area, from the coast to the Kharga Oasis.

Because of this role of the Nile Delta and Valley as an effective barrier, the fauna of Sinai and the Isthmic Desert is naturally closely related to the fauna of Gaza, as given by Zahavy and Wahrman (1957). *Dipodillus dasyurus, Meriones crassus* and *Sekeetamys calurus* can be readily identified as common nominate subspecies. Other species and subspecies erected by Osborn and Helmy (1980) for the Sinai fauna may occur with a high probability in Gaza and the Negev, such as *Gerbillus gerbillus asyutensis, Gerbillus pyramidum floweri, Meriones sacramenti, M. tristrami, Psammomys obesus nicolli, P.o. terraesanctae* and some species of the genera *Acomys* and *Jaculus*, apart from *Hystrix* and *Spalax* (two typical coastal genera). *Gerbillus nanus*, recorded from Gaza, is excluded from the Egyptian fauna by Osborn and Helmy (1980), although it is given an omni-Saharan distribution by Niethammer (1971).

On the other hand, taxa of the Western Desert are closely related with those of Libya, which are distinguished by Eisenberg (1975) into "Mediterranean" and "Desert" taxa. Among the former (ten species) eight occur in the Western Desert; and among the latter (seven species) five occur in the Western Desert. The western Mediterranean coast has acted as a corridor from which Libyan taxa could migrate southwards to the oases. Of its sixteen taxa, many remain, however, exclusively coastal: *Allactaga tetradactyla, Eliomys guercinus cyrenaicus, Dipodillus campestris wassifi, D. simoni kaiseri, Hystrix, Jaculus jaculus flavillus, Meriones shawi isis, Psammomys obesus obesus* and *Spalax*. Five could penetrate only to the northern oases: *Dipodillus henleyi henleyi, Gerbillus andersoni inflatus, G. perpallidus, Meriones l. libycus*[1] and *Pachyuromis duprasi natronensis*. Another two could penetrate further to the southern oases: *Gerbillus g. gerbillus* (which is also Nilotic) and *Dipodillus a. amoenus*. At this point it is also worth mentioning that *Dipodillus campestris patrizii*[2] and *Acomys cahirinus viator* are common to the Kufrah Oasis and Gebel Uweinat (Osborn and Krombein, 1969), whereas *Jaculus j. jaculus* (of the "Desert" group), reaches Kufrah, Gebel Uweinat, and the western bank of the Nile, and does not occur on the coast (Osborn and Helmy, 1980).

Turning attention to the southern part of our area, the records of rodents in various zones of this part are shown in Table 5.6. One may first note that Gebel Uweinat, isolated by immense expanses of vegetationless desert, has only four taxa, derived either from the Al Kufrah Oasis (Osborn and Krombein, 1969) or the Egyptian oases and the Nile Valley. Jebel Marra, also isolated but less drastically, and better endowed with rainfall (800 mm) has a richer fauna derived mainly from tropical Africa, such as *Mastomys* and *Praomys*, or from the *Acacia* parkland and shrubland of the

TABLE 5.6

Records of rodents in southern Egypt and the northern Sudan (from various sources)

GEBEL UWEINAT

Acomys cahirinus viator
Gerbillus campestris patrizii
G. gerbillus gerbillus
Jaculus jaculus jaculus

JEBEL MARRA

Acomys cahirinus cinereus
Arvicanthis niloticus centralis
Dipodillus lowei
Euxerus erythropus limitaneus
Grammomys macmillani
Heliosciurus bongensis canaster
Lemniscomys dunni dunni
L. lynesi
Mastomys kulmei
M. natalensis marrensis
Praomys fumatus
Steatomys aquilo
Tatera benvenuta benvenuta
Taterillus emini clivosus

NUBIA

Acomys cahirinus cahirinus
A. c. hunteri
Arvicanthis niloticus niloticus
Dipodillus amoenus amoenus
D. campestris venustus
D. mackillingi
Gerbillus gerbillus gerbillus
G. g. sudanensis
G. pyramidum pyramidum
Jaculus jaculus butleri

KHARTOUM

Acomys cahirinus cinereus
Arvicanthis niloticus
Dipodillus campestris venustus
Euxerus erythropus
Gerbillus pyramidum
G. stigmonyx
G. (Dipodillus) watersi
Jaculus jaculus butleri
Meriones crassus pallidus

GEBEL ELBA

Acomys cahirinus hunteri
Dipodillus amoenus amoenus
D. henleyi mariae
D. mackillingi
Gerbillus gerbillus sudanensis
G. pyramidum elbaensis
Jaculus jaculus butleri
Meriones crassus crassus
M. c. pallidus
Sekeetamys calurus makrami

[1]Which in fact is not found on the coast except at Salum (Osborn and Helmy, 1980).

[2]Formerly *Gerbillus campestris patrizii*.

southern fringe of the Sahara with 200 to 400 mm rainfall, such as the ground squirrel *Euxerus*. The Jebel Marra fauna shows the effect of elevation in segregating lowland and montane species. In the lowlands around the massif, the following occur: *Acomys lowei*, *Desmodilliscus braueri*, *Gerbillus g. agag*, *G. (Dipodillus) principulus* and *Taterillus emini perluteus*, among others (Happold, 1965, 1975). Up to about 1300 to 1600 m, the following occur: *Acomys cahirinus cinereus*, *Euxerus*, *Grammomys*, *Heliosciurus*, *Mastomys kulmei*, *Praomys*, *Steatomys* and *Tatera emini clivosus*. From 1300 to 2000 m or more, the following taxa occur: *Arvicanthis niloticus centralis*, *Gerbillus (Dipodillus) lowei* (endemic), *Mastomys natalensis marrensis*, *Tatera b. benvenuta* and the two *Lemniscomys* species. Quills of a porcupine were found (Happold, 1965).

As with birds, the Nilotic species (*Arvicanthis*) tends to spread along the southern fringe of the Sahara, differentiate into subspecies and live away from human habitation. In Jebel Marra, it was found in vegetation (Happold, 1965). *Acomys* is the only desert species living in Jebel Marra, represented by *A. cahirinus cinereus*[1] which occurs also in the Khartoum region. In Gebel Elba it is represented by *A. c. hunteri*, which also occurs in Nubia together with *A. c. cahirinus*. The Khartoum region (with about ten taxonomic entities), has the same species density as Nubia and Gebel Elba. However, it has only two entities in common with Gebel Elba: *Meriones crassus pallidus* (which also occurs in Atbara: Hoogstraal et al., 1955–56) and *Jaculus j. butleri*; and only four in common with Nubia: *Arvicanthis niloticus*, *Dipodillus campestris venustus*, *Gerbillus pyramidum* and *Jaculus j. butleri*. Nubia and Gebel Elba have five entities in common. This loss of similarity, in spite of a constant species density, denotes gradual replacement of deserticolous entities by savannicolous entities as one goes southwards. As a contrast, entities known from Nubia and Gebel Elba, such as *Acomys cahirinus hunteri* and *Gerbillus g. sudanensis*, are also known from Kassala and northeastern Sudan. This shows that, whereas tropical elements dominate Jebel Marra, true desert elements reach south to a short distance from the Ethiopian highlands. Hoogstraal et al. (1955–66) concluded that the mammalian fauna of Gebel Elba is mainly Mediterranean, especially the montane component. The presence of *Acomys* and *Jaculus* in the Red Sea region of the Sudan pushes this component further south, while the record of the Mediterranean *Psammomys obesus* in Port Sudan shows that this element is also prevalent along the coast, or at least was at some time in the past. The *Psammomys* record is quite isolated from the one near Suez (Setzer, 1956; Osborn and Helmy, 1980). However, it is similar to the case of the termite *Anacanthotermes*.

The general features of the overall pattern of distribution of rodents, reptiles and termites (all burrowing animals) have the following similarities:

(1) The Nile plays the role of a barrier between faunas of the Eastern and Western Deserts. This is most marked in rodents, less in termites and is not entirely decisive for reptiles.

(2) The Mediterranean coast has more species than the inner desert, and the fauna gradually becomes more impoverished from the northern parts of the Eastern and Western Deserts, to their southern parts.

(3) Nubia, Gebel Elba and northeastern Sudan have more or less similar faunas and show some improvement in faunal richness, whereas in the Khartoum region and the southern fringe of the Sahara there is a spreading of species towards east and west. This holds also for birds.

(4) Mediterranean elements could migrate along the Red Sea coast and remain in the area of Port Sudan as relicts.

(5) A desert fauna can be distinguished from a Nilotic fauna along the Nile Valley and in the oases, with occasional but very limited incursions of one into the habitat of the other. Interchange and freer mixing occurs in the Gezira plain, southern Kordofan and the Gedaref region because of favourable rainfall and denser vegetation.

(6) In the Western Sudan, desert rodents reach as far as the Meidob Hills [*Gerbillus (Dipodillus) principulus*] and north of El Fasher (*G. nancillus*), while tropical elements occupy the region of El Fasher (*Desmodilliscus braueri* and *Taterillus emini perluteus*) and the lower slopes of Jebel Marra. The higher slopes are occupied by an endemic *Dipodillus* and *Arvicanthis*, both cold-adapted, as well as by other species from a tropical origin. This con-

[1]Happold (1969) mentioned *A. c. cineraceus* for the gebels of northern Sudan.

trasts with the absence of tropical elements from the Red Sea mountains.

Bridges and mountains

From the preceding section, it is evident that the most prominent feature of biogeographic importance in the deserts of Egypt and the Sudan is the Nile. Its main stream serves both as a link between south and north and a barrier between east and west. These deserts are bordered on the north by a relatively rich littoral zone with clement climatic conditions linking the "Maghrebian" and "Levantine" segments of the Mediterranean biota. The broad Nile Delta forms an effective wedge between these two segments, and, as it tapers in the south in the region of Cairo, it allows the crossing of some species from the Isthmic Desert to the deserts of Wadi Natrun, Mareotis, Faiyum, and Bahariya Oasis. This can be seen in the case of rodents (as well as some other mammals) and of reptiles. It has also been shown to be a clearly discernible feature to explain the distribution of weeds in the Egyptian deserts (Kosinova, 1974a, b, 1975). One may therefore recognize a "Cairo bridge" to indicate these limited crossings. Another route, but much less effective, of exchange is along the narrow Mediterranean littoral zone of recent and indurated sand dunes at the north of the Delta, which has been described by Barakat and Imam (1973). This corridor was rather used by littoral species of northern Sinai and Mareotis. Among reptiles, there is *Acanthodactylus boskianus asper* and *Malpolon monspessulanus insignatus* (Marx, 1968), and among mammals there is probably only the hedgehog (*Hemiechinus auritus*), which has however produced a western littoral offshoot mixing with *H. a. aegyptius* in Beheira and Giza (Osborn and Helmy, 1980).

The narrow Nile Valley in Nubia has also served as a limit to the free exchange of biota between the wide floodplains in Upper Egypt in the north and the Gezira plain in the south (El-Hadidi, 1976; Ghabbour, 1976a). It also served to enable some limited exchange between the biota of Gebel Elba in the east and Gebel Uweinat and Jebel Marra in the west. This was perhaps possible mainly for "Saharo-montane" elements (Wickens, 1976a) of the flora, and for some rodents (Osborn and Helmy, 1980).

Further south, the importance of the Nile as a barrier between east and west, and as a haven for water-dependent species, becomes less marked as rainfall increases gradually, until the desert and semi-desert are transformed to savanna. Here water-dependent species and species, usually confined to vegetated areas, become widespread over the diffusely spread shrubs and trees.

Apart from the Nile as a prominent corridor, there are three other important but less obvious ones in the Eastern Desert. These are: (1) the narrow coastal plain along the Red Sea which served to carry some birds to Somalia (Moreau, 1966) as well as *Psammomys* and *Anacanthotermes*; (2) the chain of mountains which served to carry many mammals (not affected by altitude) and mosses from the Mediterranean; and (3) the succession of large wadi catchments from Wadi Tumilat between Ismailia and Zagazig, to Wadi Amur between Port Sudan and Atbara. The advance of reptiles from Sinai along this broad corridor was much less successful than that of mammals. Here again, the mountain chain serves as a barrier between the biota of the coastal plain and that of the large wadis draining into the Nile Valley (Kassas, 1971; Zahran, 1976; Batanouny, 1973, 1979). These three corridors, together, served to bring several Ethiopian elements to the flora and fauna of the Egyptian Eastern Desert. This was most marked in the case of reptiles, which are preadapted to desert conditions.

In the Western Desert, the northern part received most of its denizens from the Maghreb segment more to the west, along the Mediterranean coast or through the series of northern oases, apart from the elements obtained from the Levantine segment of the Delta's northern border or southern tip. The invertebrate fauna of the northern part of Egypt's Western Desert, together with that of the Siwa Oasis, is very similar to that of northern Libya (Hammad, 1979). On the other hand, the fauna of Gebel Uweinat is more similar to that of the Kufrah Oasis (Osborn and Krombein, 1969). The great oasis depressions served only to a very limited extent as "stepping stones" for biota. In fact, the biota of each oasis is almost entirely derived from the nearest large stock, or reserve, of species, so that each oasis has its own unique assemblage of species, depending on the near neighbour from which it has been derived.

The oases perhaps served as stepping stones for birds only, and here this is restricted to migratory birds. Even in the case of airborne fungus spores, there are marked differences in fungal flora between the northern and southern oases. As a rule, the richness of species is higher in the northern oases.

Between Gebel Uweinat and Jebel Marra, the backbone of the Darfur highlands has served as a corridor for some elements along the Hoggar and Tibesti mountains (Wickens, 1976b). These came from various sources: Ethiopian, Boreal and Saharo-montane. Otherwise, the flat Western Desert is a truly barren desert where only the hardiest plants (e.g. *Aristida*) and dependent rodents (*Jaculus* and *Gerbillus*) can survive as a persistent biocoenosis. Falcons may frequent special spots seasonally to exploit the migratory birds. The gebels of northern Sudan act, to a certain extent, as oases where a specialized flora (e.g. *Blepharis*) is protected from grazing and a specialized fauna (e.g. *Acomys*) is protected from excessive drought and predation. Both oases and gebels have a certain similarity to insular conditions. The more isolated gebels, such as Gebel Uweinat, have a remarkably poorer biota.

This picture is the result of present isolation as well as former connexions during pluvial periods, when traversing the barren deserts of today was possible under conditions of somewhat better rainfall and more extended vegetation belts. However, areas such as the Great Sand Sea are thought to have always remained hyper-arid (McBurney, 1960). The climatic and vegetational changes immediately preceding and leading to present-day conditions were summarized by Rzóska (1976) and Wickens (1976b), but it may be useful to consult the works of Butzer (1965b), Berry and Whiteman (1968), Whiteman (1971), Maley (1973, 1980), Livingstone (1975), Wickens (1975a, b), Nicholson and Flohn (1980), Williams et al. (1980), and Nicholson (1980).

HUMAN IMPACT

General

Ancient human occupation of the deserts of Egypt is very well documented (e.g. McBurney, 1960; Reed, 1977). For the Sudan, only scant evidence is available (Arkell, 1949; Balfour-Paul, 1955). Recent important findings on the early domestication of wild cereals and on settlements showing the transition from gathering–hunting in the open desert (or desertifying savanna) to more or less sedentary or semi-nomadic life near the Nile, in the Late Palaeolithic, were presented by Wendorf et al. (1979). The impact of traditional cultures which developed during the last few millennia on the ecosystem is recognized to have been considerable, but certainly not as drastic as the new developments of the twentieth century, engendered by population explosion, poverty and profiteering, and aided by modern technology (Kassas, 1967, 1970; Cloudsley-Thompson, 1971; Ghabbour, 1972b, 1974; De Vos, 1975; Baumer, 1974–75).

Five main threats to Sudan forests were identified by Dakroury (1973): over-grazing, shifting agriculture, fire, mechanized agriculture and excessive cutting of firewood (Fig. 5.6). To this one

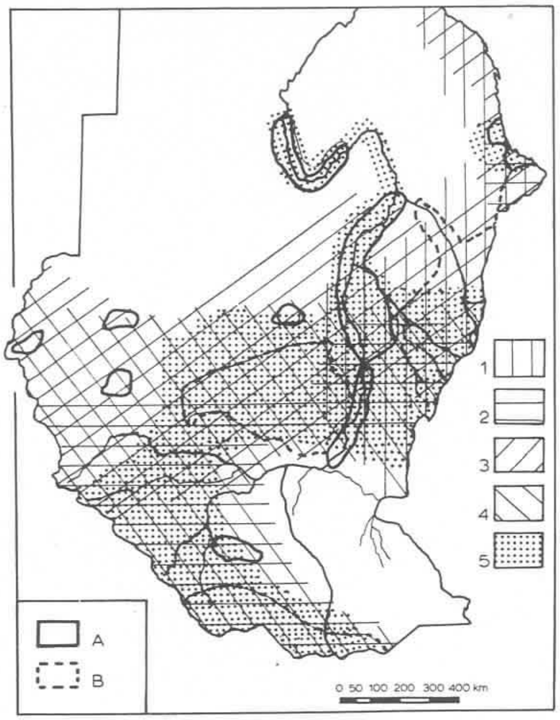


Fig. 5.6. Types and intensity of human impact on desert ecosystems in the Sudan (modified from Dakroury, 1973): *1* = over-cutting of firewood; *2* = fire; *3* = over-grazing; *4* = shifting cultivation; *5* = government schemes for agriculture; *A* = natural vegetation almost completely removed; *B* = natural vegetation partly removed.

may add the digging of more than 700 wells in the middle latitudes of Darfur, Kordofan and Kassala Provinces, which encouraged nomads to settle and to increase water consumption so that demand exceeded supply; the result was what is known as the "Thirst Belt", which was very severe in the late 1960s and the early 1970s (Fig. 5.7) and is still rampant. In the western Sudan, people and cattle gathered around the water points and destroyed vegetation and soil around them (Ghabbour, 1972b). In the Gedaref region, over-exploitation of parts of the area is a major problem, where it is perversely often a consequence of ample rather than meagre water supplies after their development (Graham, 1969).

Shifting agriculture, best exemplified by its most economic form in the southern desert fringe between the isohyets of 300 and 800 mm, was beneficial and viable as long as it was maintained. It started to succumb, again in the 1960s, due to population and economic pressure, by forced shortening of the phases of the cycle. Thus, at 14°N *Acacia senegal* (the gum-arabic tree) is replaced by *Acacia* desert scrub (which has disappeared from 16°N). In the middle part of the *A. senegal* belt, the notorious *Calotropis procera* first invades and then is replaced by other trees, or *A. nubica* invades and is followed by a mixed *Acacia* community of a less arid affinity than the *Acacia* desert scrub (Kassas, 1970). South of the 400-mm isohyet regeneration of *A. senegal* is successful, and there is evidence that *A. senegal* replaces the combretaceous parkland between the 500- and 900-mm isohyets (Fig. 5.8). The socio-economic consequences of such an encroachment have already made their effects felt. Over-grazing in Darfur and Kordofan has been encouraged by establishing a slaughter-house and a tannery in Nyala (Fig. 5.9) and a milk-drying factory in Babanusa, with a capacity of 50 tons per annum (now used for drying juice).

However, by far the greatest threat to the desert and semi-desert ecosystems of the Sudan is mecha-

Fig. 5.7. Women carrying pots and cans to obtain water from the Khartoum–Nyala train at one of its stops west of Kosti. This was a routine scene during the late 1960s in the "Thirst Belt" of the central Sudan (photo S. Ghabbour).

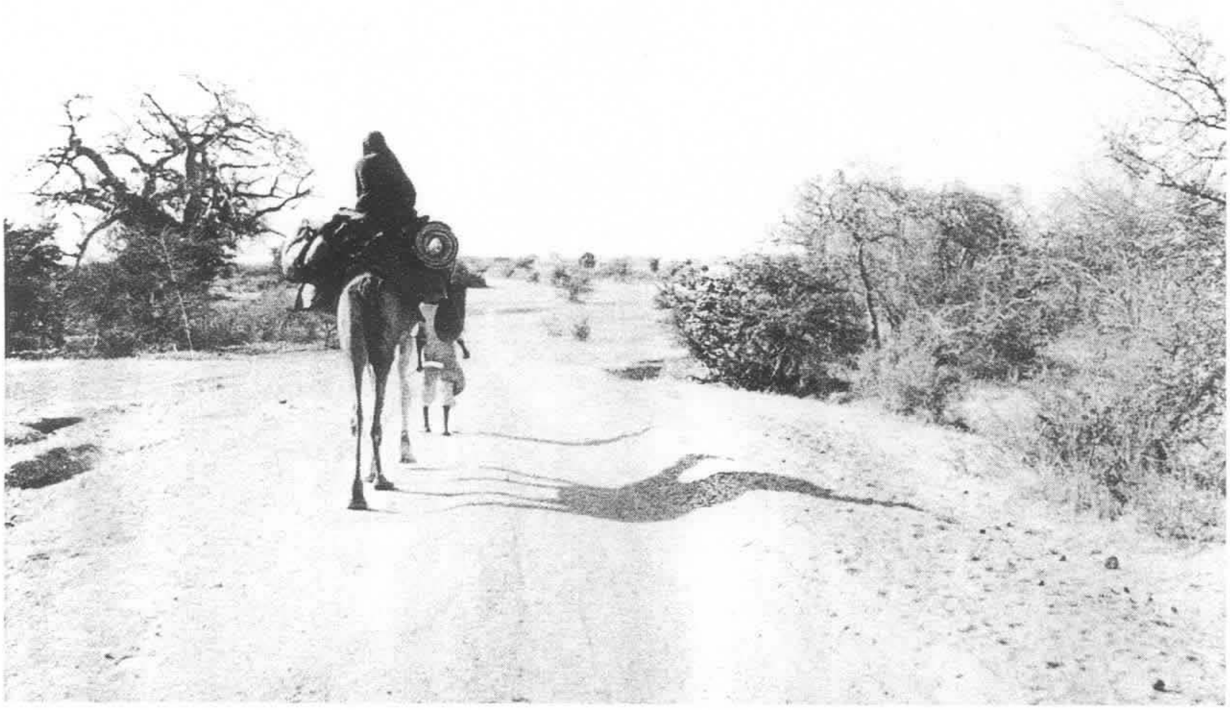


Fig. 5.8. A Baggara family on the move in the *Acacia* forest near Nyala. Note the baobab tree on the left (photo S. Ghabbour).

nized agriculture (Table 5.7). It started on a large scale in the 1960s by the encouragement of adventurers to clear large areas in the Gedaref area, each being given holdings of 5000 to 10 000 feddans (2100–4200 ha), facilities to buy tractors, and permission to clear all vegetation from the holding, plough it, and use it for dry-farming of sorghum. Yields were high and so was profit. But after one to three years the yields were almost nil and the land was abandoned. New lands were given to new or the same adventurers to repeat the same story. No one was concerned with the fate of the abandoned plots as long as new plots were being exploited. In the western Sudan, mechanized agriculture was more under government control, but its effects were more spectacular because of the flat terrain and the lower rainfall. In 1974, the Sudan Government proposed to the United Nations a project to combat desert encroachment. It was based on the observed decline in productivity in rain-fed farms. Examples were provided from Kordofan by comparing production in 1960–61 with that in 1971–72; for groundnuts the figures were 952 and 214 kg ha^{-1} respectively, for sesame 914 and 214 kg ha^{-1}. It was recognized that the contributive factors were all man-made. The threat was to the great economic potential of Darfur and Kordofan, the provinces most affected by desert encroachment, which have large Government agricultural schemes, one million hectares of private farming schemes, 75 to 80% of the world's production of gum arabic, and 28 million head of cattle, sheep, goats and camels (Ghabbour, 1975c). Further evidence of deterioration was provided by millet yields in Kordofan (Ibrahim, 1978). These closely followed rainfall till 1969, but declined dramatically from 610 kg ha^{-1} in 1969 to 250 kg ha^{-1} in 1973 with 250 mm rainfall. A rainfall of 217 mm in 1966 produced a yield of 460 kg ha^{-1}. The entire belt between 12° and 16°N in the west and between Port Sudan and Gedaref in the east is considered as a zone of strong desertification. Rapp (1976) showed, by comparing surveys published between 1958 and 1975, that the approximate desert boundary[1] moved 100 to 150 km to the south, with

[1]That is, land devoid of woody plant cover.

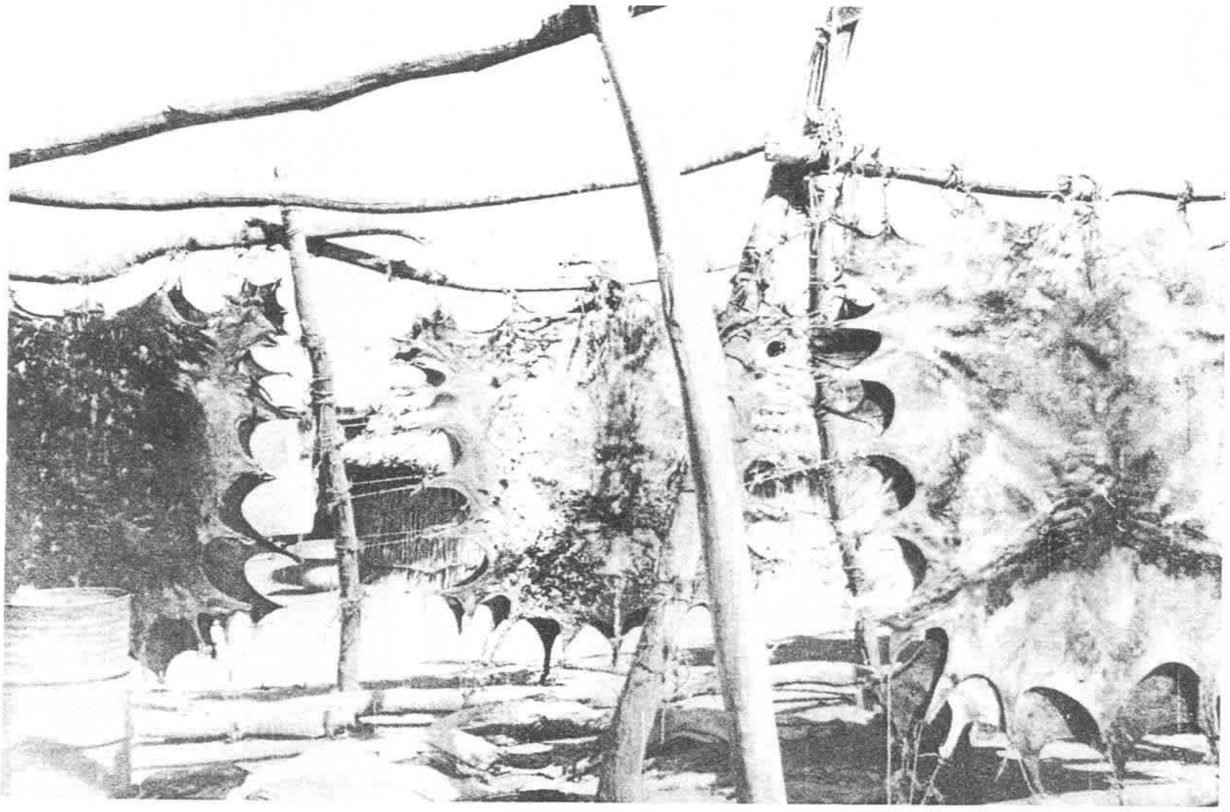


Fig. 5.9. Drying hides of slaughtered cattle at the Nyala abattoir. The introduction of organized trade in cattle and their products is profoundly changing the pattern of nomadic life in Darfur and Kordofan, and redistributing the impacts of human pressure in the region (photo S. Ghabbour).

TABLE 5.7

Mechanized farming areas in the Sudan (after Mann, 1975, source: Dr. Shazli, Director, Mechanized Farming Corporation, Khartoum) (1 feddan = 0.42 ha)

Province	Area cultivated 1973/1974 (feddans)	Target amended in the five-year plan (feddans)
Kassala	1 853 000	2 223 000
Blue Nile	880 600	2 000 000
Upper Nile	300 250	450 000
Kordofan	140 000	747 400
Darfur	10 000	570 000
Total	3 184 250	5 990 400

extensive protruding areas of mobile dunes further south. Ahmad (1979) estimated a drop of 80% in groundnut yield, of 95% in sesame yield, and of 89% in other crops in Kordofan — as well as low productivity of 6 to 8% for livestock. Moreover, Musnad (1979) estimated that the area deforested in the Sudan between 1958 and 1978 was about 200 000 km^2 (1.6 ha per minute!).

In spite of these well-known facts, projects for mechanized farming are proposed for more ambitious expansion on the same old plans, as shown in Table 5.7. This expansion is further encouraged by the prospect that the Sudan could become the Arab World's bread basket, and the consequent investment of petro-dollars. The poor yield of dry-farming has been attributed to fluctuating rainfall (Mann, 1975), so that "fluctuation" of yield is confused with "decline" of yield. Thimm (1979), while still holding rainfall fluctuation to be a major cause, recognized the "tendency" of most projects to show decreasing yields after initial high values, and that this pointed to the serious impact mechanized farming "may" have on the environment.

Finck (1973) has enumerated the effects of the shifting cultivation system on soils, as changes in mineral components, organic components (humus and soil biota), in particles (structure), and in the soil as a whole (soil profile). These changes are naturally much more drastic than those caused by grazing, and less so than those caused by mechanized agriculture. The main concern of these projects is "permanence", but the depletion of soils started immediately after the first cropping year (Thimm, 1979) and a fallow in the crop rotation proved to be a major difficulty. Other remedial measures, which may also prove to be difficult, include the introduction of a rigorous crop rotation, restriction of cropping to years of favourable rainfall, the application of fertilizer, the better observation of soil conservation techniques, etc. For the success of new schemes, proper surveys are necessary, to avoid selecting them haphazardly. Proper motivation and participation of the local population, usually neglected, are of vital importance. Against these rational views, some economists still speak of the Sudan's "vast, unexploited expanses of land" and "large water reserves" and advocate intensification of agricultural production by the increase of yields, by the increase of mechanization, the reduction of the time when the land is left fallow, and the increased use of fertilizer and plant-protecting agents[1] (Kiss, 1977). The future of the food-producing potential of these arid and semi-arid ecosystems will depend on which of these two voices will be heard by the Sudan's people and decision-makers.

Andreae (1965) urged that types of farming dependent on rain, to substitute for the obsolete shifting cultivation, and ones that would prevent the destruction of soil fertility within a short time, must be invented. Such systems have barely been investigated. In the tropical savanna climate, and even more so in the tropical shrub-steppe climate, rotations of field crops and grass must be considered. Final solutions, however, have still to be found. Sprinkler irrigation is more favourable to soil fertility than surface irrigation. Special problems of soil fertility present themselves in dry tropical areas. It is endangered by high stocking rates. It depends on the amount and type of livestock and forage management. Soil fertility problems are expected to appear as economic development proceeds into an intermediate stage where over-stocking is possible but forage management is not yet practicable.

The effect of protection from grazing on the vegetation of the area near Khartoum was studied by Halwagy (1962). Even for a short time, protection exerted a favourable influence on vegetation, no artificial planting being required. The effect on invertebrates has already been summarized above.

The irrigated areas of the Sudan deserts (the Gezira Scheme) were the subject of intensive studies to recognize the effect of irrigation on soil properties (Finck, 1963). Outlying areas of the irrigated Gezira farms in the north and west had a soil salinity above 5‰ while well-drained areas in the middle, east and south had a soil salinity below 2.5‰. The former areas comprised 35% of the area of the Scheme and the latter 40%.

According to Gewaifel and Younis (1978), the xeric climate limits the amount and duration of water movement and successive wetting and drying. The seasonal migration of cotton-picking workers from Darfur, Kordofan and Kassala Provinces has caused the spread of urinary schistosomiasis in a broad belt, about 250 km wide, across these Provinces (Malek, 1978).

In another recent irrigation scheme on the Atbara (the Khashm El Girba), it is unfortunate that irrigated agriculture competes with animal husbandry and causes deterioration of pasture, instead of being integrated with it (Sörbö, 1977). Elsewhere in the western Sudan, government sedentarization efforts are said to lack clear purpose, and are based on the elimination of livestock and the encouragement of farming. Again, what is required is the incorporating of livestock resources in settlement projects. Voluntary settlement is also another phenomenon produced by new economic changes. As a result, new nomadic characteristics are emerging. These include changes in animal types, the mobile social units, the length of movement and the route and pattern of migration (El-Arifi, 1974–75).

Status of wildlife

No doubt wildlife, especially mammals, has been declining in the deserts of Egypt and the Sudan in the twentieth century. This has been documented

[1]A polite term for pesticides

for Egypt by Russell (1949), Ghabbour (1975a), Hafez (1977) and Osborn and Helmy (1980), among others; for the Sudan, by Cloudsley-Thompson (1969b, 1973, 1974, 1977b) and Wilson (1980). Earlier extinctions during the Neolithic were on a much larger scale and were due either to the Neolithic revolution of animal domestication and settlement, or to a hyper-arid desiccation which secondarily also intensified the competition between man and wildlife (Reed, 1970; Dumont, 1978). The decline of the twentieth century may also be associated with desiccation, but it is certainly more related to firearms and mechanized vehicles (cars, and now helicopters). The power of the petro-dollar was added to make the situation hopeless. Accounts of wholesale murder of wildlife, with a particular predilection for gazelles and ostriches, are commonplace[1]. In northern Darfur, there are records of at least 31 species of larger mammals, but only 6 were seen in aerial surveys in 1976, although a small number of others still survive. Only very small numbers of addax and dama gazelle still occur, while the scimitar-horned oryx and the barbary sheep may have disappeared. Carnivores were systematically exterminated in the 1940s and early 1950s (Wilson, 1980).

The few attempts to protect wildlife in deserts either terminated tragically after a brief success, or are now threatened with termination. In Egypt, Wadi Rishrash in the Eastern Desert was protected from 1900. In a few years' time, vegetation was so dense that it looked like an irrigated oasis. Wild desert mammals took refuge there for the breeding season (Russell, 1949). The reserve was destroyed in 1952. In the Sudan, the Dinder National Park is very near to the desert fringe, where the open savanna gradually merges into light forest. *Acacia fistula*, *A. senegal*, *A. seyal*, *Balanites aegyptiaca* and *Hyphaene thebaica* form this forest (Cloudsley-Thompson and Cloudsley-Thompson, 1969). The Park seemed remote from serious human destruction, but it is now faced by encroachment of "man" and his authorized and non-authorized activities. This time the expansion of legal and illegal mechanized agriculture is the main threat, with its secondary consequences of pushing grazing animals into the Park, settlement within the Park, poaching and cutting trees for charcoal (Abu Shama, 1981).

On the occasion of the declaration of the World Conservation Strategy and the Statement from the Egyptian President's Office on 5 March 1980, a National Programme for Nature Conservation has been prepared by the Egyptian National committee for IUCN (Kassas, 1981). This includes proposals to establish a network of nature reserves in the following regions:

Sinai: parts of the coasts of the Gulf of Aqaba and the Gulf of Suez, Tiran Islands, the southern mountains (St. Catherine and Musa), the northern central plain (Maghara), and the Bardawil and Tina sebkhas.

Eastern Desert and Red Sea: the region of Gebel Elba (with scientific collaboration of the Sudan), the region of Gebel Shayib El Banat, mangrove forests at Hamata and Wadi Allaqi.

Western Desert: Ras El-Hekma, El Maghra Oasis, Gebel Uweinat and Gilf Kebir.

It is hoped that this Programme will meet with approval from the authorities, and that the existing laws which prohibit wanton killing of wildlife will be enforced.

Wilson (1978) reported that crocodiles, which were fairly abundant and commonly to be found in Darfur and especially in the streams and pools around Jebel Marra early in the twentieth century, are now confined to only two sites in that Province.

Osborn and Helmy (1978) reported that, of the Egyptian rodents, the species that are "threatened" are those upon whose territories land reclamation projects are encroaching. These species are therefore those inhabiting the coastal area and areas adjacent to the Nile and the oases, namely *Allactaga*, *Jaculus orientalis*, *Nesokia*, *Psammomys obesus* and *Spalax*.

APPENDIX I: THE SINAI PENINSULA

The Sinai Peninsula, separated from the rest of Egypt by the Gulf of Suez, is distinct in many respects from the rest of the country and constitutes a transition between the Egyptian deserts on the one hand, and those of the Middle East on the

[1]Even Gebel Elba, which was thought remote and inaccessible, is now invaded by marauding hunting parties which come with jeeps by boat from across the Red Sea (D. Treville, pers. commun, 1981).

other. Accordingly, an *ad hoc* treatment in an Appendix seems appropriate.

Climate

Sinai can be distinguished climatically into two parts, according to a recent report (Anonymous, 1982): a northern part, from the Mediterranean coast to 30°N, and a southern part south of this latitude.

The northern part

In winter, this part experiences a temperature range of 7 to 20°C, but a drop to below zero may occur inland. In spring, temperatures vary from 13 to 26°C, but *khamsin* winds may cause a rise of temperature to 40°C. Summer temperatures vary from 18 to 33°C. Autumn temperatures are similar to those of spring or are slightly higher (15–30°C).

Rainfall on the coast is 80 to 100 mm per annum, with 80 mm at the northwest corner and 100 mm at El 'Arish. Rainfall decreases gradually southwards until it reaches 50 mm at 30°30'N, and 25 mm at Nakhl, but may rise again due to altitude in the highlands in the southern edge of this part, to 50 to 75 mm. Most rainfall is in December and January, with frequent records of 30 mm in one day. Thunderstorms are frequent in spring and autumn, and may cause destructive flash floods.

The relative humidity of the air is about 70% on average on the coast, and decreases to 40% inland. The mean minimum is 30 to 40% at 15:00 h local time, and maxima may reach 90% on the coast in the early morning. During the *khamsin*, relative humidity may drop to as low as 10%.

The southern part

During winter, temperatures near the Red Sea coast vary from 13 to 23°C, and may drop to −10°C in the highlands. The ranges for spring, summer and autumn are respectively: 20 to 30°C (40°C in the *khamsin*), 25 to 25°C, and 20 to 30°C. Rainfall does not exceed 20 mm yr^{-1} on the Red Sea coast, and 50 to 70 mm in the highlands. The maximum is usually in spring rather than in winter.

Relative humidity is 60%, on average, in the southern tip between the two Gulfs, and 50% in the highlands. The diurnal and the annual ranges of variation do not exceed 10%, except again during the *khamsin*, when it drops markedly (Anonymous, 1982).

Geomorphology

The Sinai Peninsula has, as a core near its southern end, an intricate complex of high, very rugged igneous and metamorphic mountains (Said, 1962). The northern two-thirds of the Peninsula is occupied by a great northward-draining limestone plateau which rises from the Mediterranean coast and terminates in a high escarpment on the northern flanks of the igneous core. The igneous core is formed of mountains which represent the highest peaks in Egypt: Gebel Katherina (2641 m), Gebel Umm Shomar (2586 m), and Gebel Serbal (2070 m). These mountains and their deep rocky gorges form one of the most rugged tracts in the country.

The higher part of the limestone plateau which flanks the igneous core to the north forms Gebel El-Tih. The central portion of the plateau drains to the Mediterranean by numerous affluents of Wadi El 'Arish. The eastern and western edges are dissected by numerous narrow wadis draining into the Gulfs of Aqaba and Suez.

In the northern part, the plateau surface is broken by hill masses of Gebel Yi'allaq (1090 m), Gebel Halal (890 m) and Gebel Maghara (735 m). These are separated from the Mediterranean shoreline by a broad belt of sand dunes, some of which attain heights of more than 100 m above sea level.

Vegetation

Boulos (1982) estimated that Sinai contains almost 1000 higher plant species, almost 40% of the Egyptian flora. It harbours about sixty endemics, mostly concentrated in the southern highlands. The unique geographical position of Sinai, linking Asia and Africa, and not very far from Europe, is reflected in its unique flora (see p. 164 above). This geographic position explains the presence of species characteristic of the Mediterranean littoral, as well as those of the high mountain chains extending to Iran in the east and to the African subtropics in the south. With these different origins and the diversity of the Sinai habitats, Boulos (1982) distinguished the vegetation of the Peninsula into eight regions:

(1) Remnants of the coniferous forests made up of *Juniperus phoenicia* in the northern mountains of Halal, Maghara and Yi'allaq.

(2) Dwarf montane vegetation including about thirty endemic species and characterized by *Hypericum sinaicum*, *Phlomis aurea*, *Primula boveana*, *Veronica musa*, etc., occupying the high mountains of southern Sinai.

(3) Mediterranean semi-arid vegetation, including *Ballota undulata*, *Capparis spinosa*, *Centaurea eryngioides*, *Kickxia aegyptiaca*, *Phagnalon rupestre*, *Teucrium polium* and *Verbascum sinuatum*, occurring north of the southern highlands.

(4) Arid vegetation, represented by *Anabasis articulata*, *Astragalus spinosus*, *Atriplex halimus*, *Cornulaca monacantha*, *Gymnocarpos decandrum*, *Peganum harmala*, *Tamarix nilotica* and *Zilla spinosa*, occurring north of region 3.

(5) Coastal sand dunes, having *Ammophila arenaria*, *Cakile maritima*, *Cyperus conglomeratus*, *Euphorbia paralias*, *Silene succulenta*, *Pancratium maritimum*, etc. The saline marshes adjacent to the dunes have a vegetation dominated by *Arthrocnemum glaucum*, *Frankenia hirsuta*, *Halocnemum strobilaceum*, *Limoniastrum monopetalum*, etc. These are more common on the Mediterranean coast.

(6) Hot deserts near the southern coasts, characterized by *Acacia tortilis* (specially common in the southern wadis), mixed with *A. raddiana*, *Aerva javanica*, *Calotropis procera*, *Capparis decidua*, *Cassia italica*, *Ochradenus baccatus* and *Ziziphus spina-christi*, as the prominent species. Such a vegetation, it will be recalled, extends south along to the Nubian Desert and the Dongola Reach (Sudanese Nubia) to the area of Khartoum, except that *Ziziphus* disappears at a much more northerly latitude.

(7) Psammic arid area, between the Mediterranean coast and region 4, characterized by perennial grasses and including *Artemisia monosperma*, *Retama raetam*, and *Stipagrostis plumosa*.

(8) Mangrove vegetation at Ras Muhammad in the southern tip of the Peninsula, with *Avicennia marina*.

Rabinowitz (1980) considered the high mountain region of Sinai a well-defined "island" of Central Asian steppe vegetation, as a relict of the Irano-Turanian Zone that covered most parts of the Middle East during colder and wetter periods in the past, leaving behind entities which became endemics. Trees originating from the mountain steppe–forest belt are found living with plants typical of the Alpino-Tragantic belt in Central Asia. Among the trees, *Crataegus sinaica* and *Pistacia khinjuk* are typical. They are members of the low, open steppe–forest formations in the mountains of Iran and Afghanistan. *Pistacia* is also found in Gebel Elba. The two aforementioned species occupy different habitats in the Sinai mountains: *Pistacia* in cracks and cliffs, and *Crataegus* in the flat wadi beds with deep soil. The Alpino-Tragantic vegetation is represented by short bushes of the cushion type, like *Astragalus echinus* and *Bupleurum falcatum*. Endemics within this group include *Atraphaxis spinosa*, *Phlomis aurea* and *Pyrethrum santolinoides*. Endemics of the more remote central mountains include *Hypericum sinaicum*, *Primula boveana*, *Pterocephalus sanctus* and *Thymus decussatus*. An even more curious fact is that annual plants show a similar pattern of distribution, occurring in Sinai and Iran without a connexion, such as *Lappula sinaica* and *Paracaryum intermedium*. Only two Mediterranean species occur in this high mountain region: *Ballota undulata* and *Majorana syriaca*. In the lower altitudes with warmer habitats endemics from the surrounding Sudanic and Saharo-Arabian vegetation elements are also found, such as *Linaria sinaicum*, *Phagnalon sinaicum* and *Varthemia montana*[1].

Danin (1981) investigated the effect of creating new human settlements in eastern Sinai on its vegetation. These were in alluvial fans with a dominant vegetation comprising *Acacia raddiana*, *A. tortilis*, *Hammada salicornica*, (= *H. elegans*) *Hyoscyamus boveanus*, and *H. muticus*. The newly emerged vegetation was established as a result of the meeting of elements from five different origins which were: (1) desert ruderals, exemplified by *Hyoscyamus muticus*, *Malva parviflora* and *Peganum harmala*; (2) species of desert springs, such as *Alhagi maurorum*, *Imperata cylindrica*, *Juncus arabicus*, *Polypogon monspeliensis* and *Tamarix nilotica*; (3) species of other desert habitats, such as *Asparagus stipularis*, *Calotropis procera*, *Kickxia acerbiana*, *Suaeda monoica*, *Tribulus bimucronatus* and *Zilla spinosa*; (4) common weeds derived from nurseries, of wide mesophytic occurrence; and (5) newly arrived "xenophytes", such as *Aster subulatus*, *Atriplex semibaccata*, *Kochia indica*, two *Conyza* species, and four *Euphorbia* species, among others.

[1]Now *Jasonia montana*.

The similarity of this synanthropic flora with that of gardens near the Monastery of St. Catherine is rather low (21%). However, it added fourteen new species to the floral list of Sinai. This is a large proportion indeed for just a small coastal strip.

Fauna

According to Wassif (1982), Sinai can be divided as regards its fauna into the same two parts again: the sandy flat north and rocky rugged south. The northern Sinai fauna comprises the red fox (*Vulpes vulpes*), the fennec (*Fennecus zerda*), the gazelle *Gazella dorcas*, the hedgehog *Hemiechinus auritus*, the mole rat *Spalax ehrenbergi*, the fat sand mouse (*Psammomys obesus*), and the locally extinct *Hystrix indica*, among mammals. Reptiles include the skink and the horned viper. The southern Sinai fauna is characterized by the hyrax, the ibex, the Sinai leopard (*Panthera pardus*, which some insist on calling *Leopardus jarvisi*, not seen for more than fifty years), the caracal [*Felis* (*Caracal*) *caracal*, also extinct], the larger hedgehog *Hemiechinus dorsalis*, the rodents *Sekeetamys calurus* and *Acomys russatus*, among mammals. A large reptilian fauna is also well represented. Mammals common to both areas include the jerboa *Jaculus jaculus*, the gerbil *Gerbillus gerbillus*, the hare *Lepus capensis*, Rüppel's fox (*Vulpes rueppelli*), and the hyaena (*Hyaena hyaena*).

Rabinowitz (1980) found a high diversity of the fauna of the central highlands and attributed it to the diverse origins of the vegetation. An interesting species among birds is the Sinai rose finch (*Caprodaicus sinaicus*), which dwells in the high valleys and mountain tops in summer and descends to lower areas during the severe winter. The fox is the common predator. The Sinai leopard might reappear if the increase of the ibex population during the 1970s is maintained.

Bahaa-El-Din (1982) considered Wadi Firan the western limit for birds of Asiatic origin dwelling in Sinai. He pointed out the importance of Ras Muhammad at the southern tip of the Peninsula as a convergence point for many migratory birds coming from Eastern Europe and Western Asia. He further considered that about 80% of the storks from these regions pass through that point. When they arrive they are so tired that they can be caught by hand very easily; they are hence exposed here to severe risks. Furthermore, he estimated that raptors migrating through this point reach several million individuals and may well constitute 100% of the migratory raptors of the areas of origin. They fly at an altitude of about 3 km, and this saves them from shooting or capture. The islands near Ras Muhammad constitute the northernmost extension of Indian Ocean seabirds. They too undergo severe pressures from hunters and tourists.

Traditional land use

Rabinowitz (1980) mentioned the outstanding fruit gardens run by the Gebaliya Tribe associated with the Monastery of St. Catherine, in the upper valley of their area. The rugged red granite rocks enable some soil to accumulate in depressions. This is the basis of their agriculture, when the soil is wetted by the rains. Close to 400 gardens, each just a tiny spot surrounded by rocks, are known today. The fruit trees are mainly deciduous and cold-adapted varieties, some of them endemic. Calculations have shown that a full-scale garden, well taken care of, can produce the energy requirements of two parents and a child. The gardens are inhabited during the summer as part of a transhumance cycle, but some have been forsaken in the last few years as bedouins become engaged in tourist summer resorts on the coast!

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